Measurement of XYZ → $\Lambda\bar{\Lambda}\phi$

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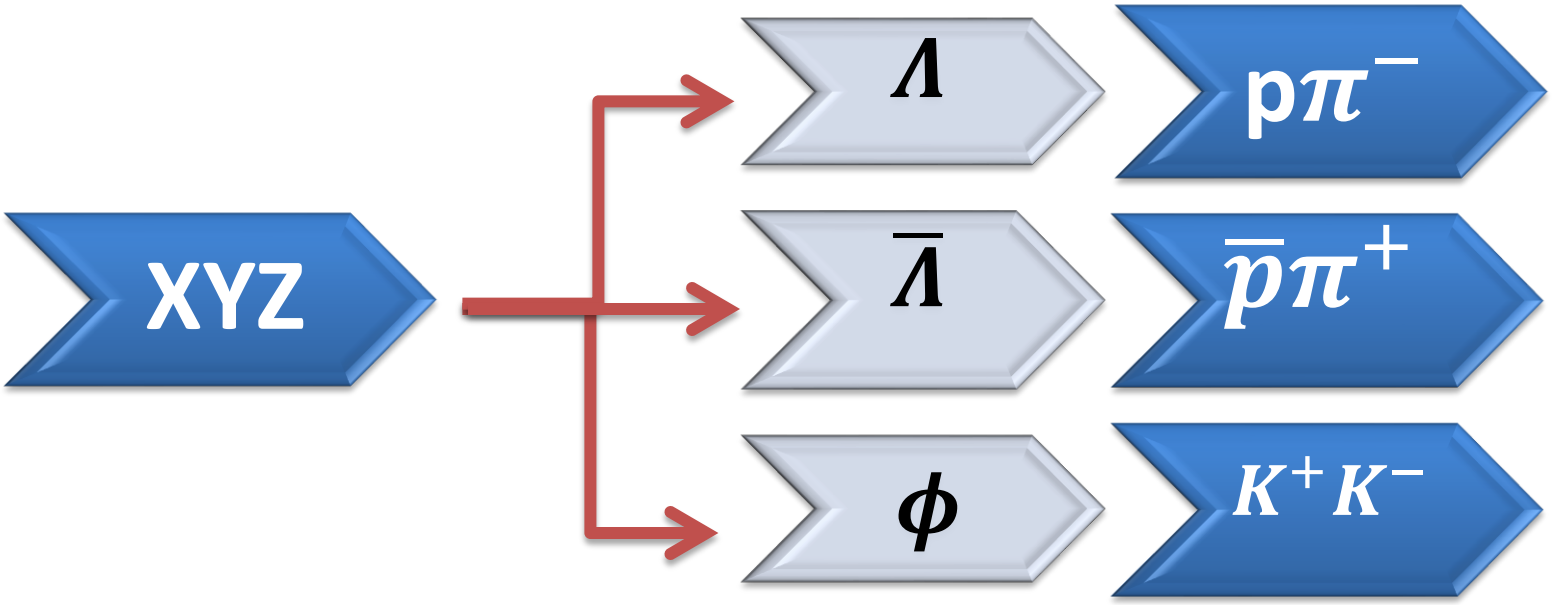
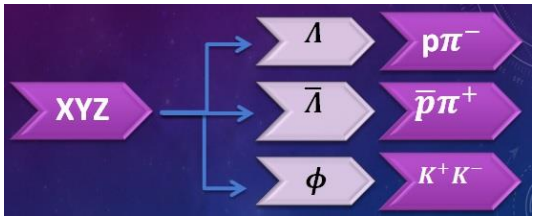
Highlights

- *Our decay process*
- *Data sample and MC simulation*
- *Initial event selection criteria*
- *Kinematic fitting*
- *XYZ → $\Lambda\bar{\Lambda}\phi$ plots*
- *Final event selection*
- *Background analysis*
- *Detection efficiency*
- *Cross section calculation of XYZ → $\Lambda\bar{\Lambda}\phi$*
- *Systematic uncertainty estimation*
- Statistical significance of ϕ signal
- *Summary and analysis results*

Our Decay Process



Data Sample and MC Simulation

- The analysis is performed under BOSS framework of 7.0.3 version.
- Phase Space (PHSP) model is used to study 

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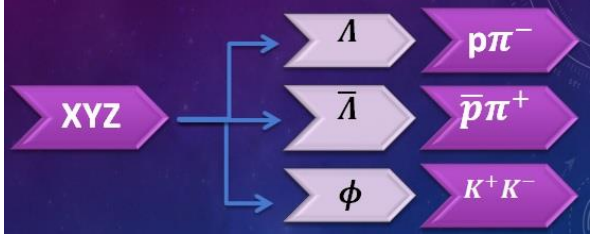
- Three kind of files used for analysis including (signal and exlusive MC root file) , inclusive MC data root file and real data root files. 500 pb^{-1} Inclusive data sample of Y(4260) is used for background analysis. Details of real data is given in table.
- Signal and exclusive MC root files are generated for 100,000 number of events while inclusive and real data root files are generated for 1 x 10^9 number of events.

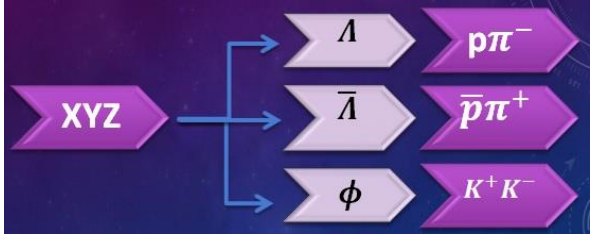
Data Sample	Center of mass energy $\sqrt{s}$ (GeV)	$\mathcal{L}(pb^{-1})$	Run No.
Real	4.190	522.5 ± 0.1 ± 3.4	47543-48170
	4.200	424.6 ± 0.1 ± 2.5	48172-48713
	4.210	518.1 ± 0.1 ± 1.8	48714-49239
	4.220	514.3 ± 0.1 ± 1.9	49270-49787
	4.237	530.6 ± 0.1 ± 2.4	49788-50254
	4.246	537.4 ± 0.1 ± 2.6	50255-50793
	4.260	828.4 ± 0.1 ± 5.5	29677-30367, 31561-31981
	4.270	529.7 ± 0.1 ± 2.8	50796-51302
	4.280	175.5 ± 0.1 ± 0.9	51303-51498

Initial Event Selection Criteria



- One missing charged track technique is used. For 6 charged tracks, total electric charge should be equal to 0 and for 5 charged tracks (for missing charged track) the resulting net electric charge is +1 or -1.
- All the charged tracks are selected that lie with in the polar region of $|\cos(\theta)| < 0.93$.
- Each charged track is required to be within the interaction point in xy plane $V_{xy} = \sqrt{v_x^2 + v_y^2} < 10.0$ cm and in z direction $|v_z| < 15.0$ cm.
- Each track having transverse momentum $P_{xy} > 0.05$ GeV are selected and sent for further filtration.

Kinematic Fitting



One missing charged track technique is used for kinematic fitting.

- For 6 (all) charged tracks only those events are selected that contain $N_p = 1,\ N_{\bar{p}} = 1,\ N_{\pi^+} = 1,\ N_{\pi^-} = 1,\ N_{K^+} = 1$ and $N_{K^-} = 1.$
- 4C fit is applied to the hypothesis $XYZ \rightarrow p\,\bar{p}\,\pi^+\pi^-K^+K^-$ by applying conservation of total energy and momentum.
- On the other hand for events having 5 (one missing) identified charged tracks from $p, \bar{p}, \pi^+, \pi^-, K^+ and K^-$ leads to the condition

$$N_p \leq 1,\ N_{\bar{p}} \leq 1,\ N_{\pi^+} \leq 1,\ N_{\pi^-} \leq 1,\ N_{K^+} \leq 1 \text{ and } N_{K^-} \leq 1.$$

- 1C fit is applied for one of the following hypothesis:

$$XYZ \rightarrow p\,\bar{p}\,\pi^+\pi^-K^+(K^-\ missing)$$

$$XYZ \rightarrow p\,\bar{p}\,\pi^+\pi^-K^-(K^+\ missing)$$

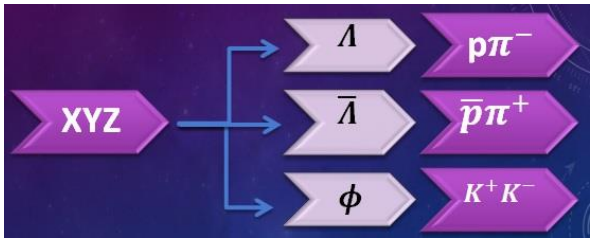
$$XYZ \rightarrow p\,\bar{p}\,\pi^+K^+K^-(\pi^-missing)$$

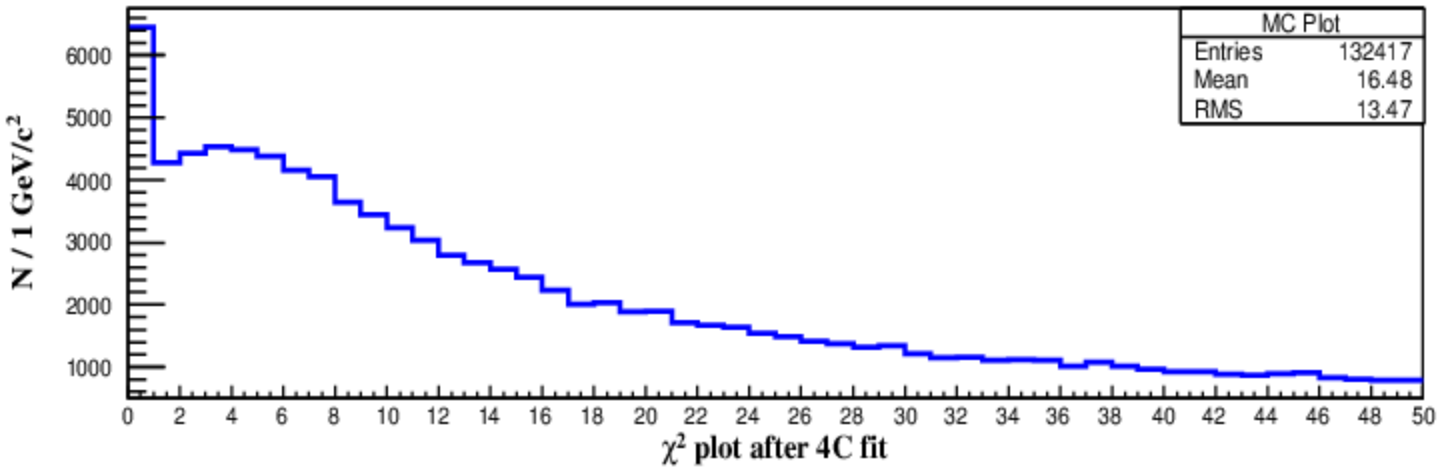
$$XYZ \rightarrow p\,\bar{p}\,\pi^-K^+K^-(\pi^+\ missing)$$

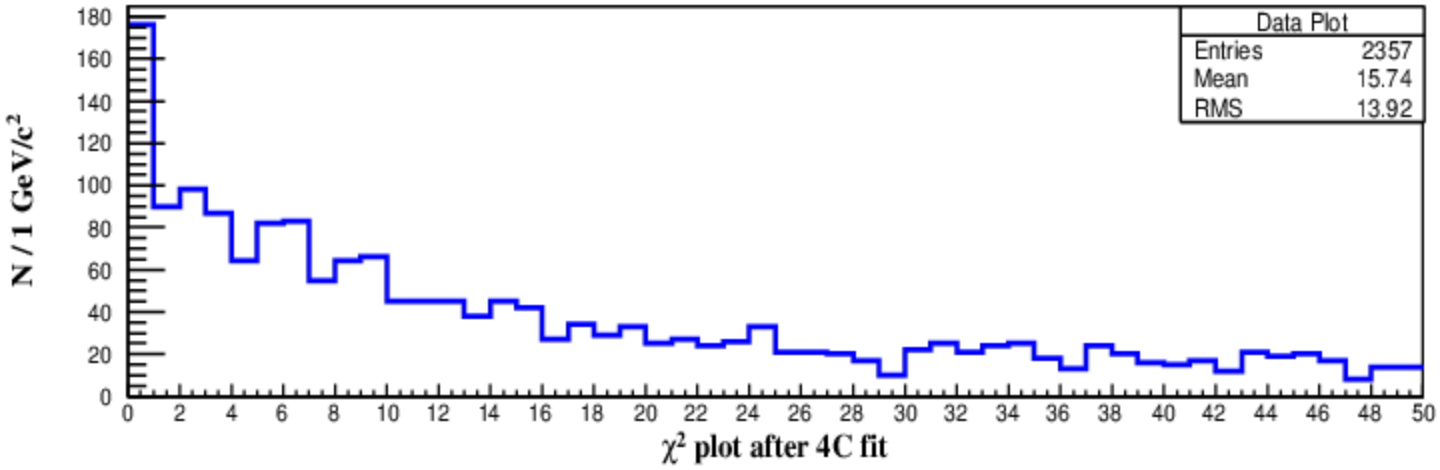
$$XYZ \rightarrow p\,\pi^+\pi^-K^+K^-(\bar{p}\ missing)$$

and $$XYZ \rightarrow \bar{p}\,\pi^+\pi^-K^+K^-(p\ missing)$$

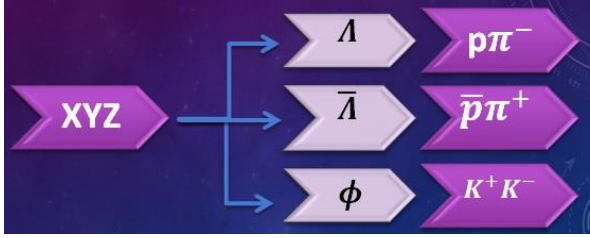
χ^2_{4c} Kinematic Fit Plot

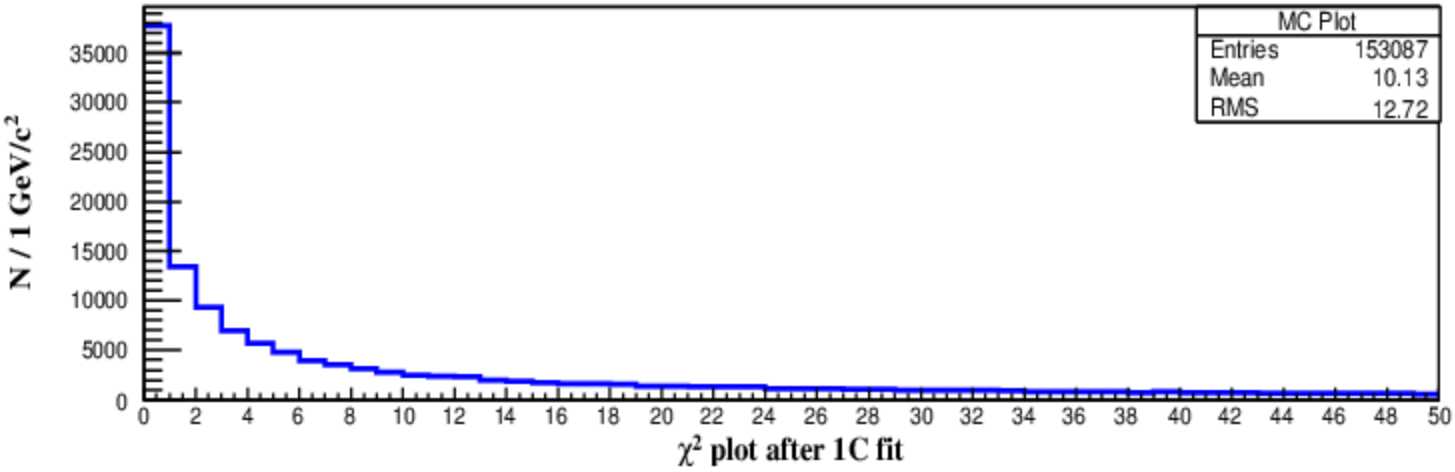


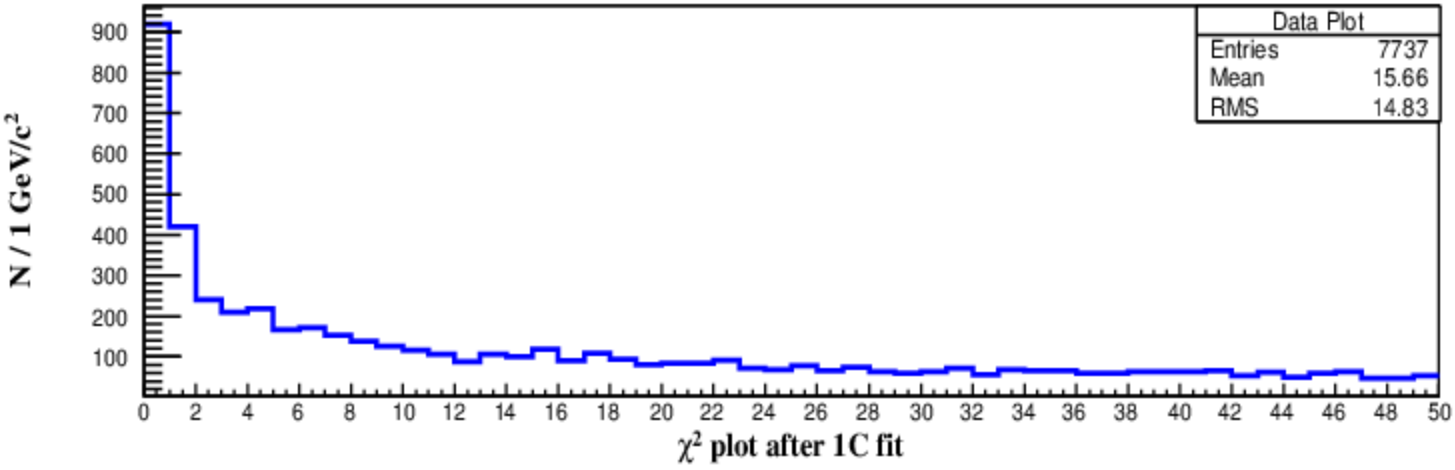




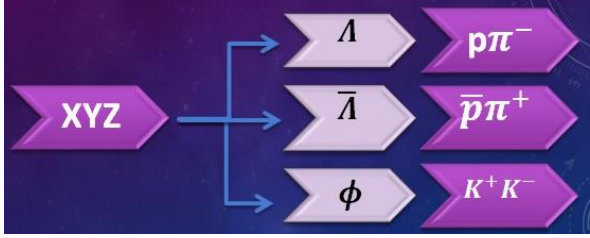
χ^2_{1c} Kinematic Fit Plot

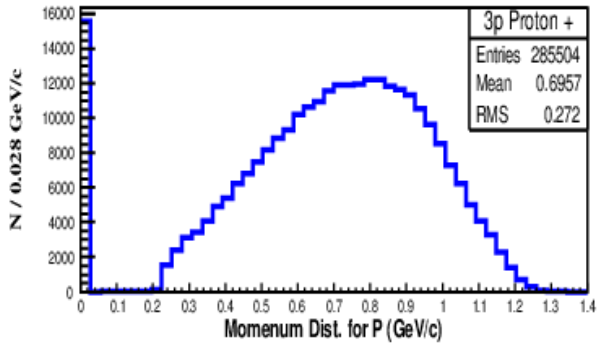


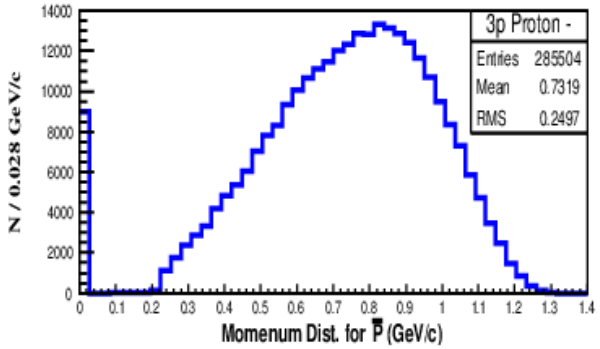


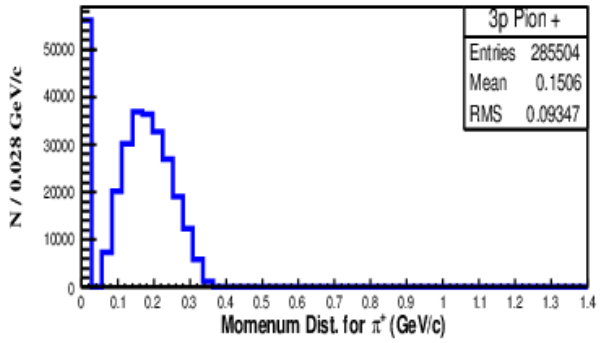


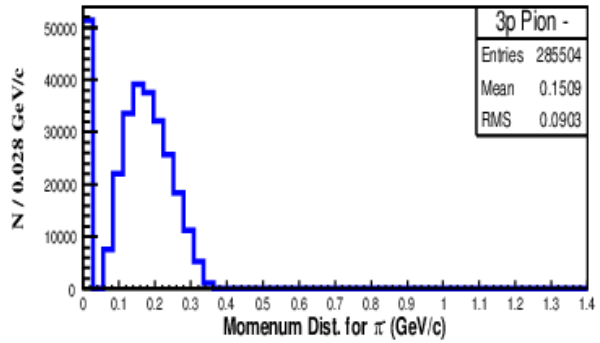
Momentum Distribution after 4C and 1C Kinematic Fit

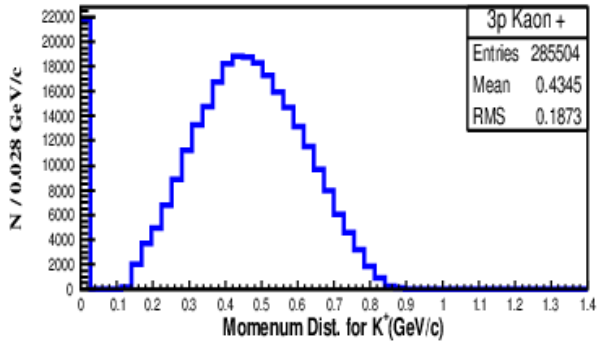


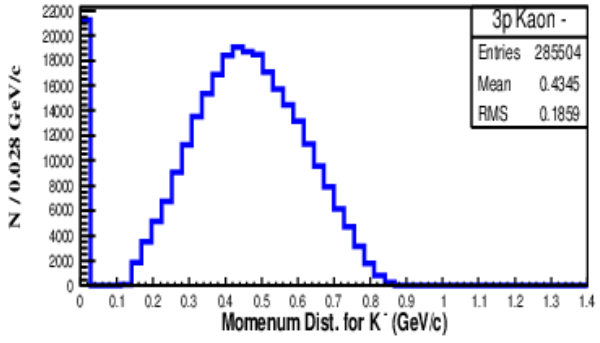




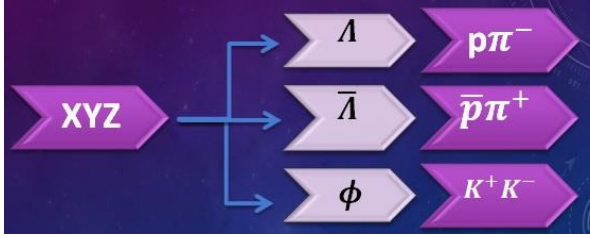


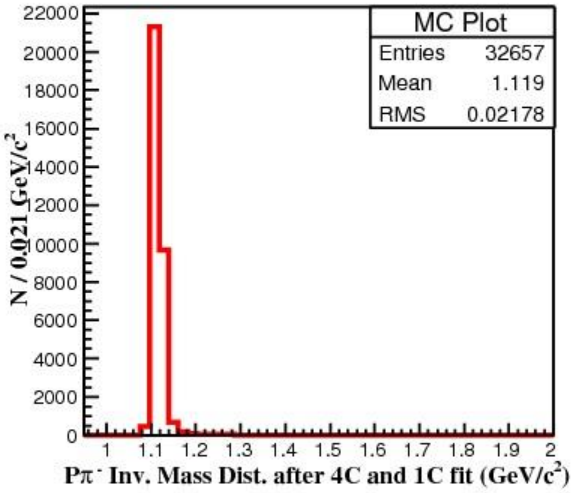


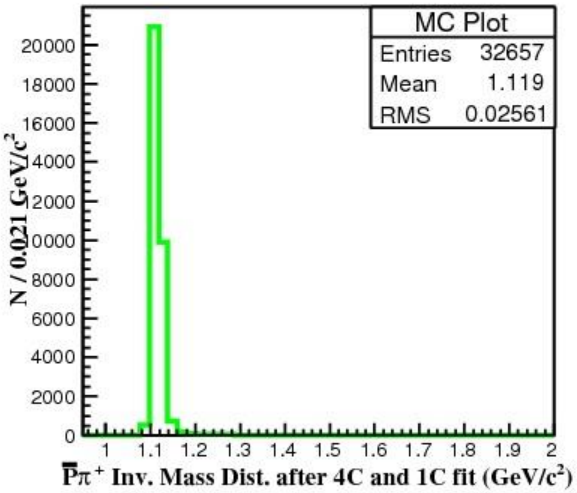


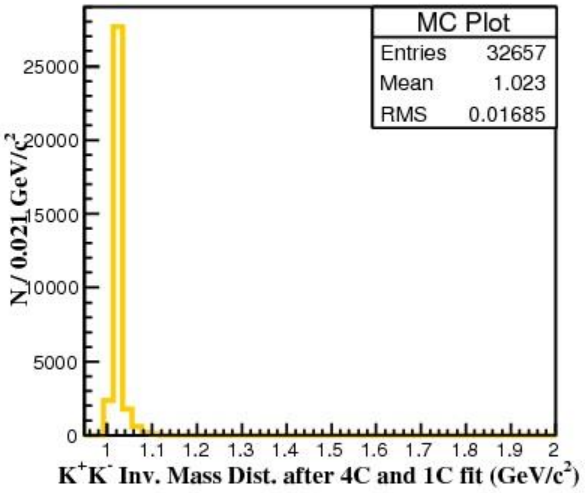


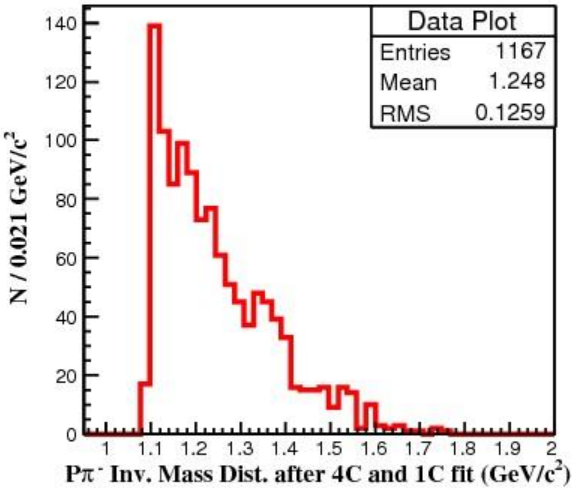
Invariant mass distribution of $p\pi^-$, $\bar{p}\pi^+$ and K^+K^- for (MC and DATA) of 4190 MEV energy after kinematic fit and without mass, χ^2_{4c} and χ^2_{1c} cuts

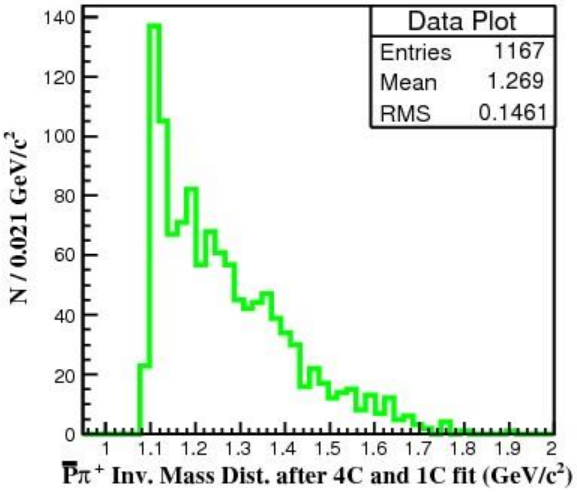


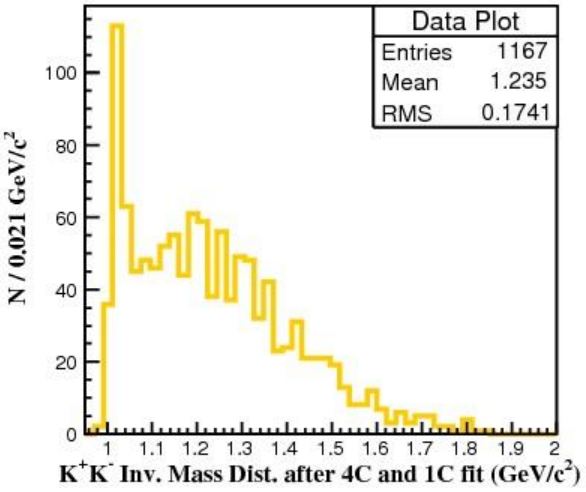




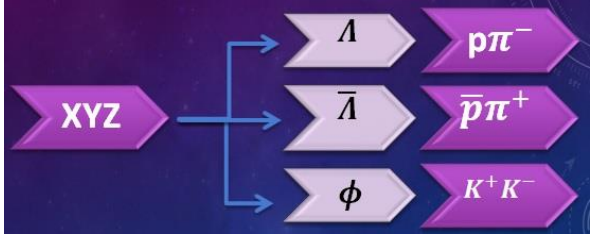


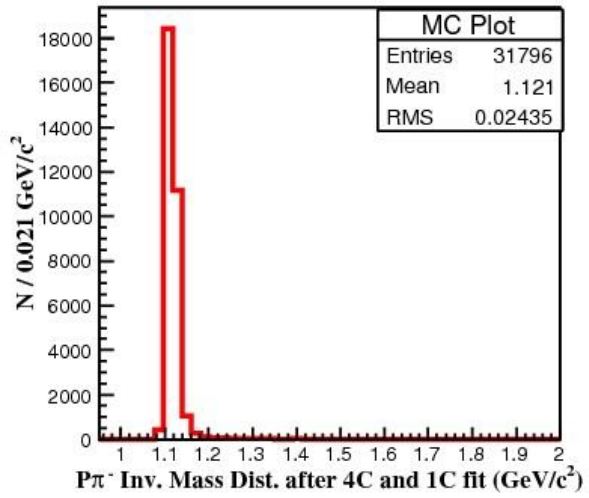


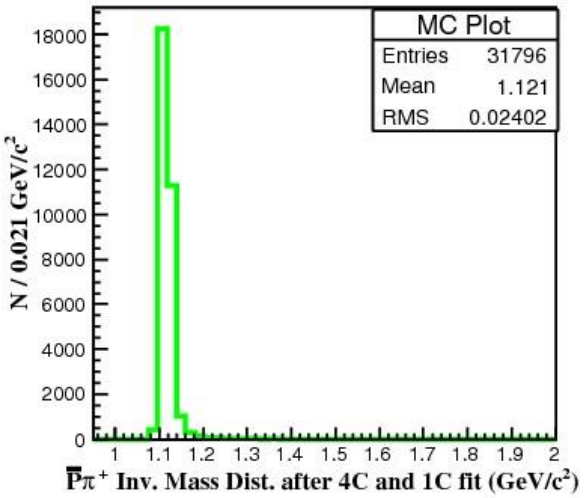


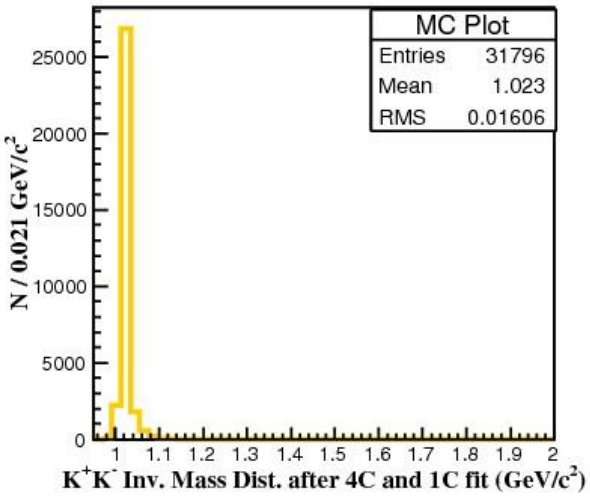


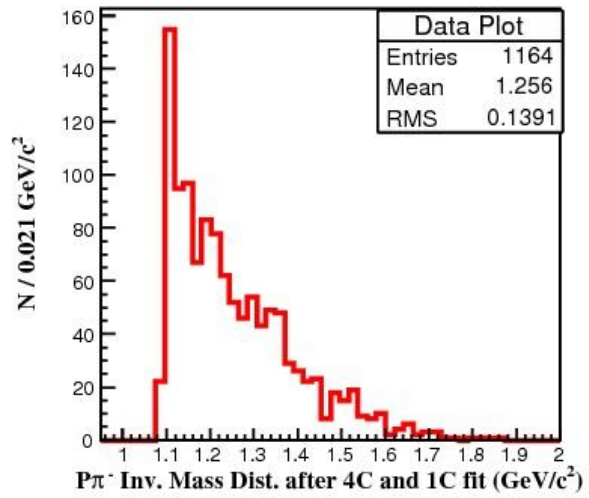
Invariant mass distribution of $p\pi^-$, $\bar{p}\pi^+$ and K^+K^- for (MC and DATA) of 4200 MEV energy after kinematic fit and without mass, χ^2_{4c} and χ^2_{1c} cuts

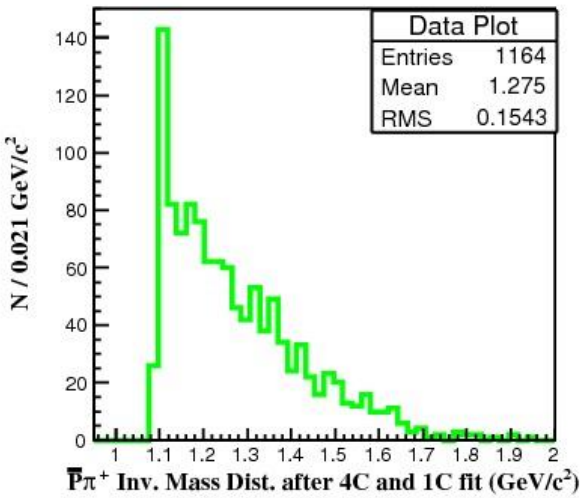


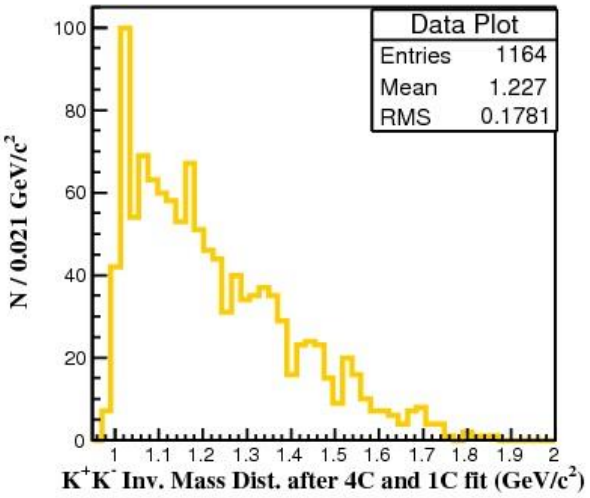




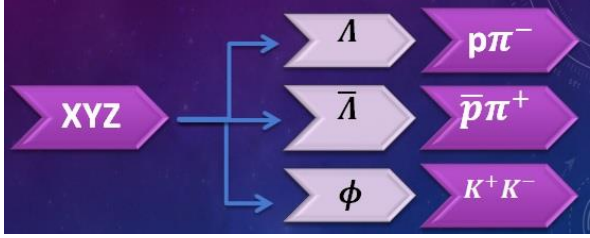


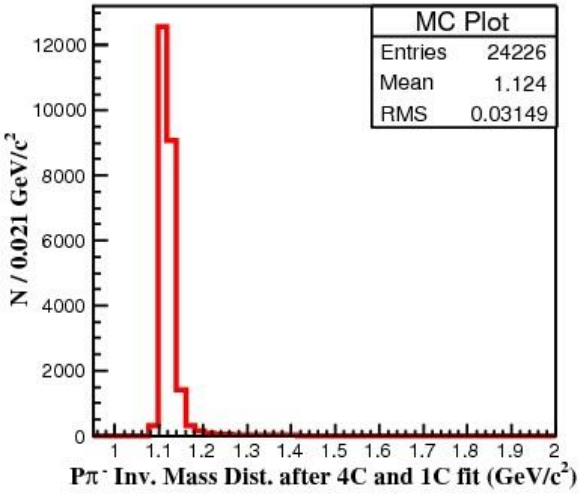


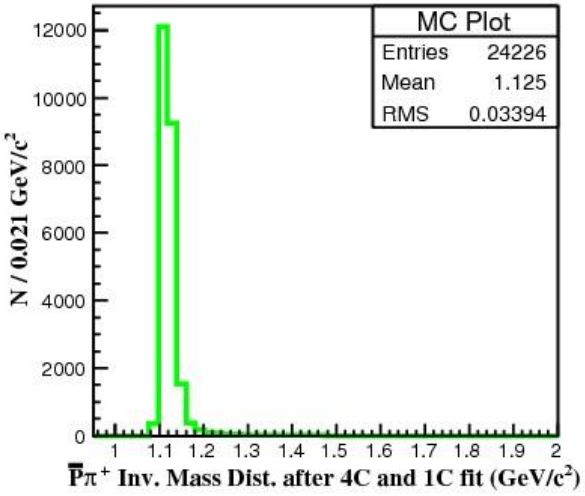


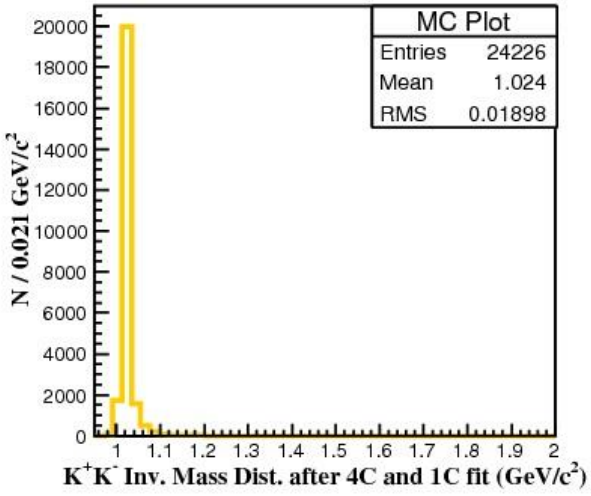


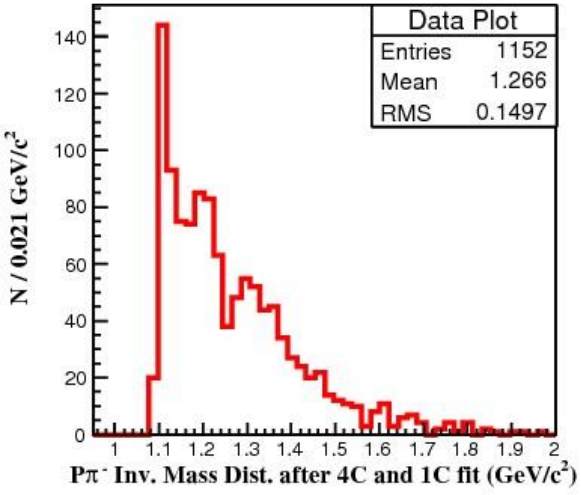
Invariant mass distribution of $p\pi^-$, $\bar{p}\pi^+$ and K^+K^- for (MC and DATA) of 4210 MEV energy after kinematic fit and without mass, χ^2_{4c} and χ^2_{1c} cuts

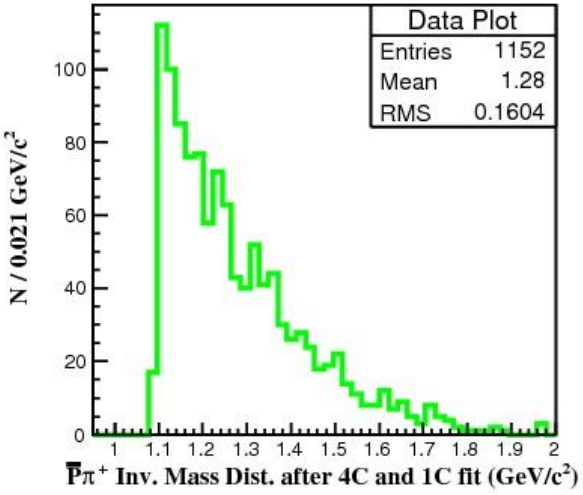


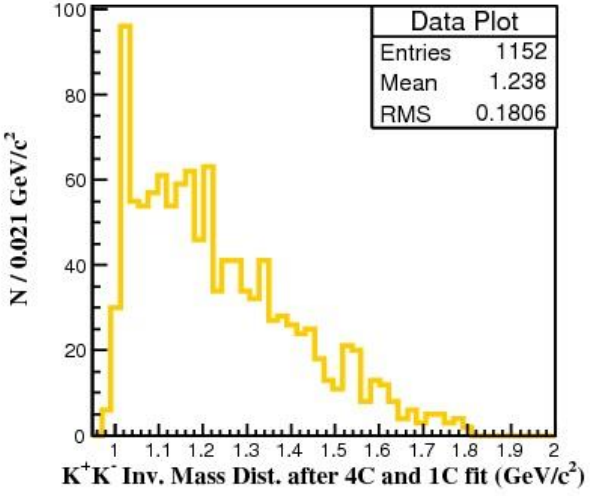




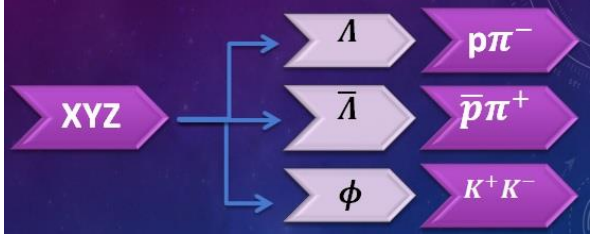


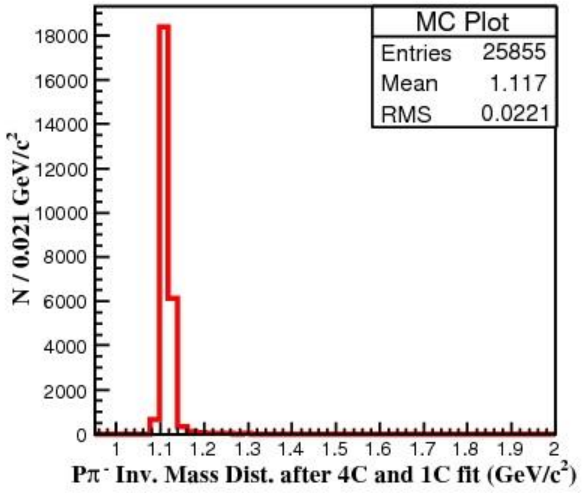


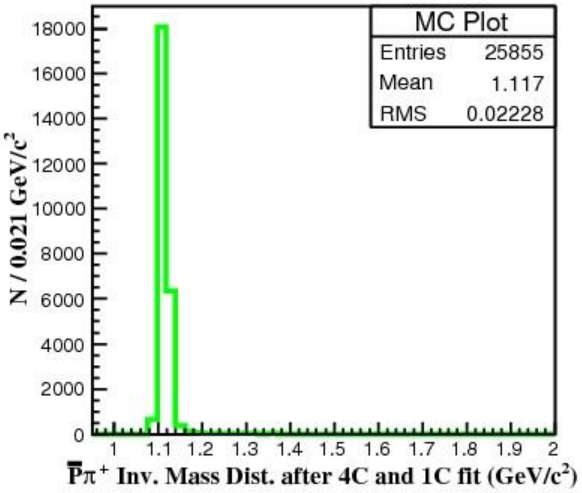


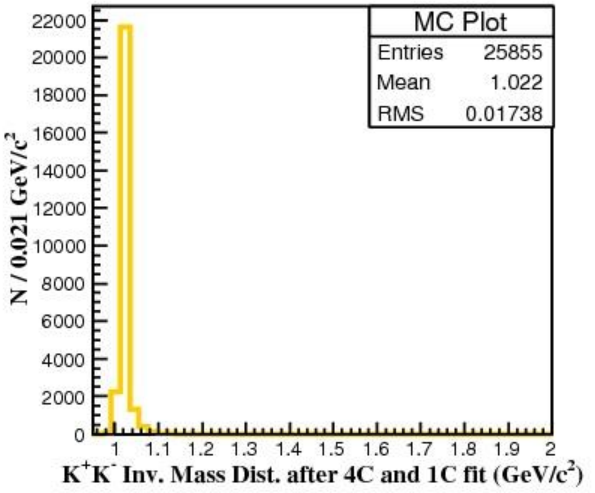


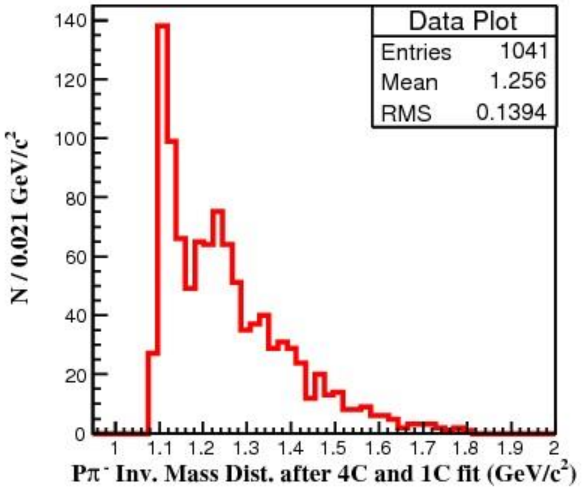
Invariant mass distribution of $p\pi^-$, $\bar{p}\pi^+$ and K^+K^- for (MC and DATA) of 4220 MEV energy after kinematic fit and without mass, χ^2_{4c} and χ^2_{1c} cuts

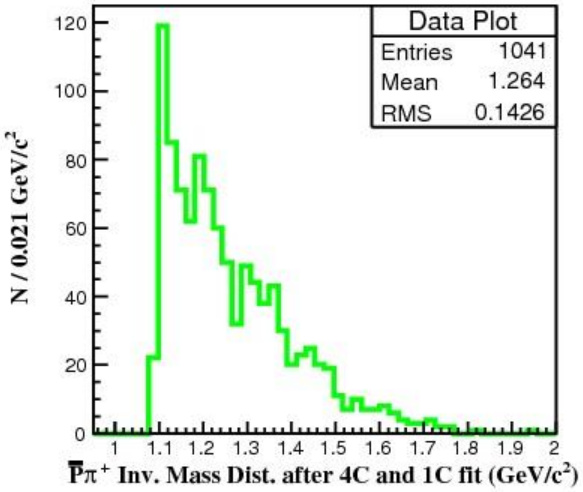


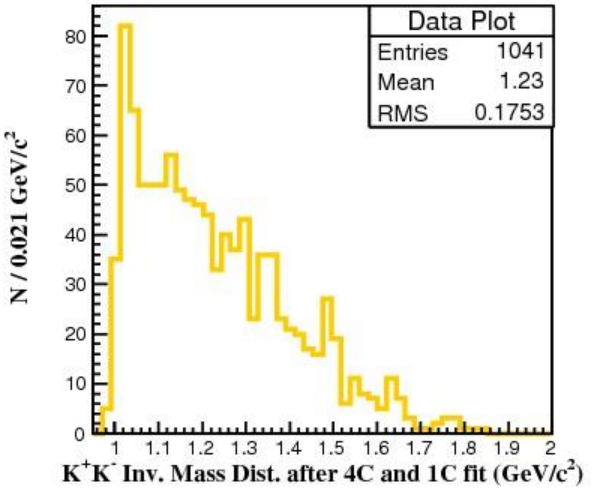




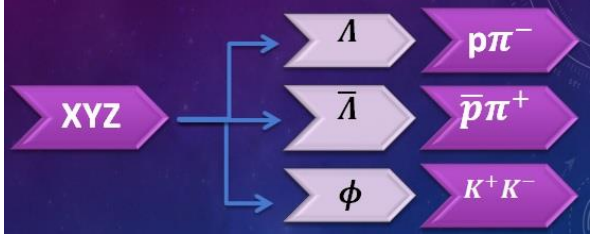


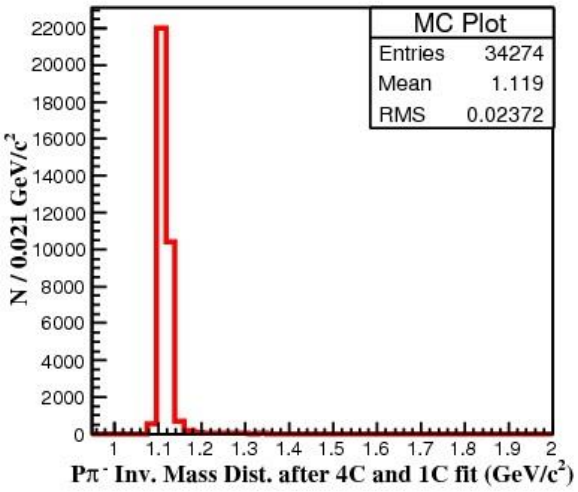


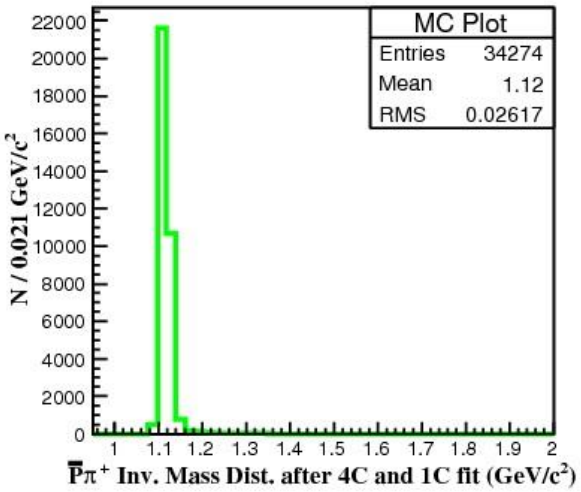


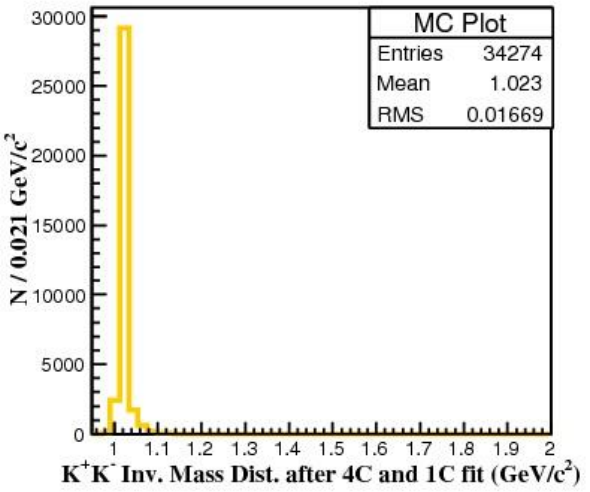


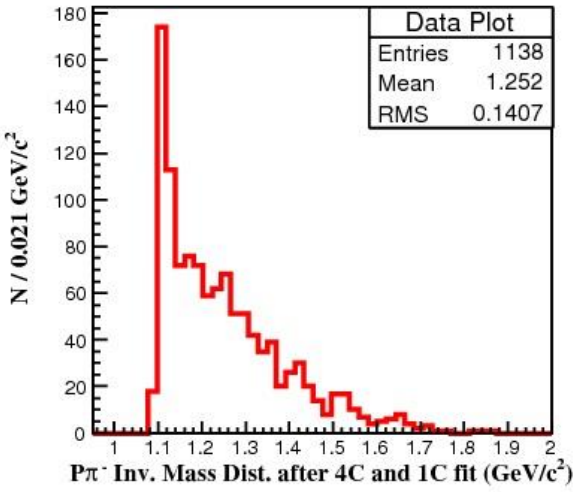
Invariant mass distribution of $p\pi^-$, $\bar{p}\pi^+$ and K^+K^- for (MC and DATA) of 4237 MEV energy after kinematic fit and without mass, χ^2_{4c} and χ^2_{1c} cuts

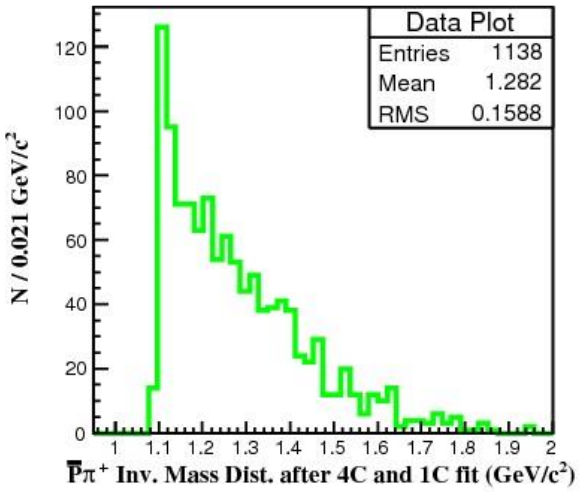


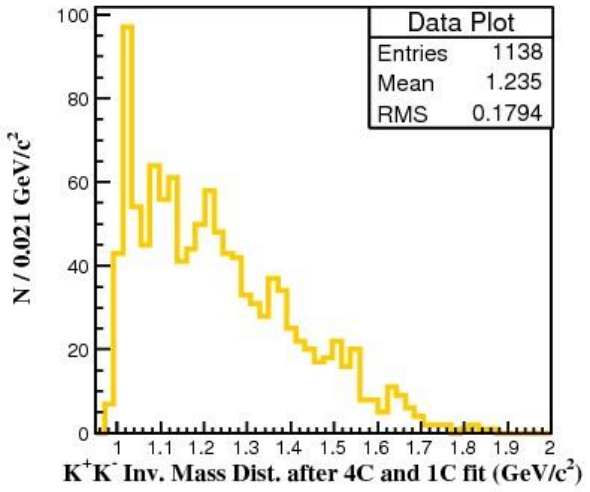




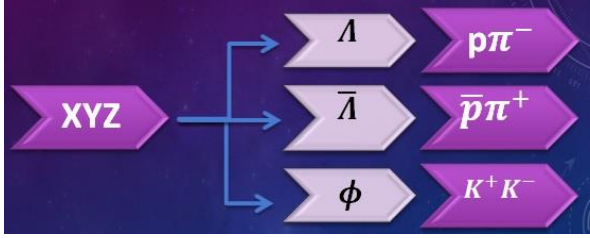


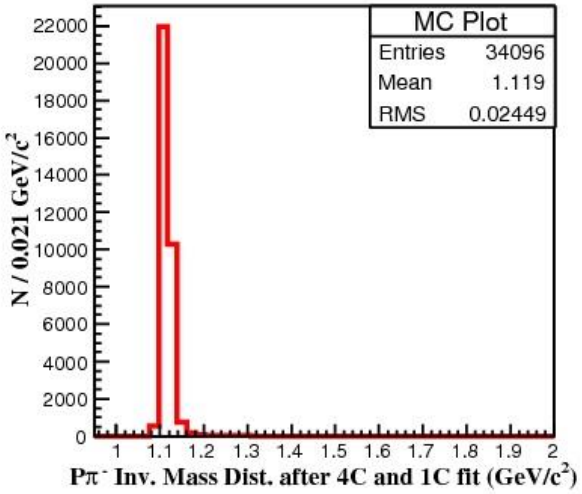


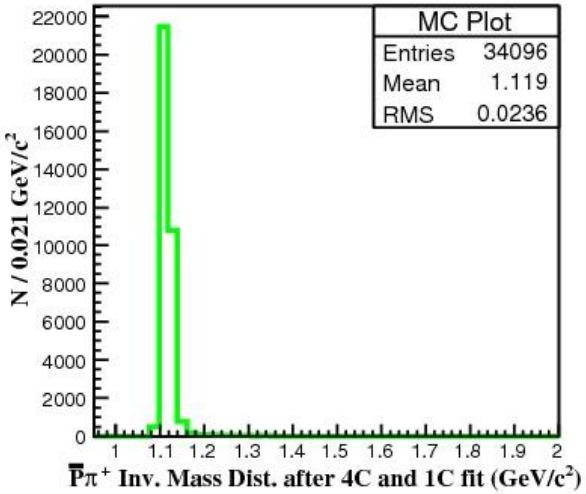


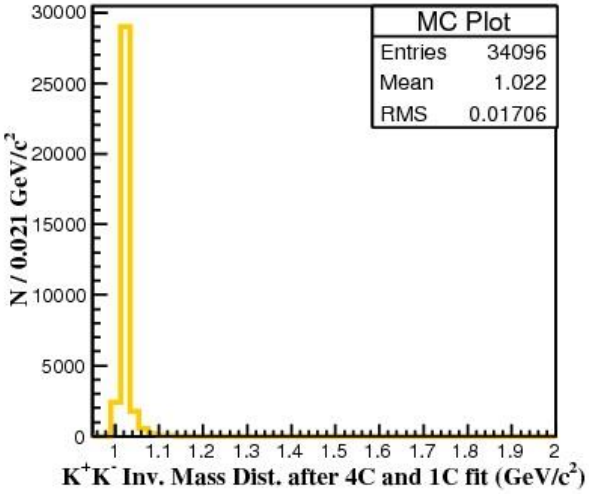


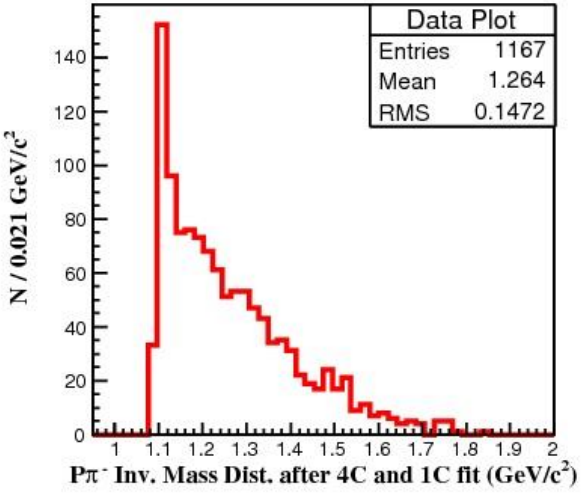
Invariant mass distribution of $p\pi^-$, $\bar{p}\pi^+$ and K^+K^- for (MC and DATA) of 4246 MEV energy after kinematic fit and without mass, χ^2_{4c} and χ^2_{1c} cuts

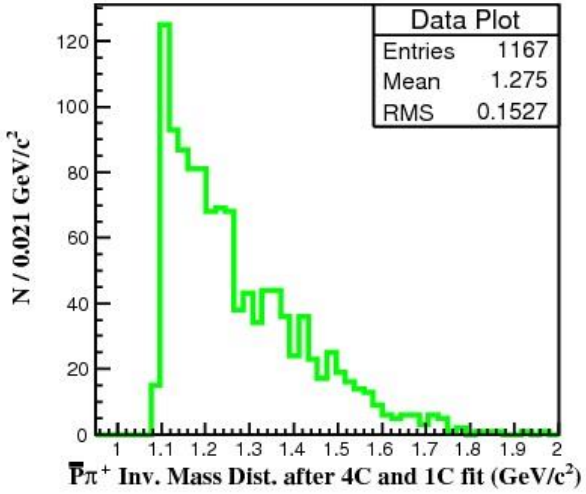


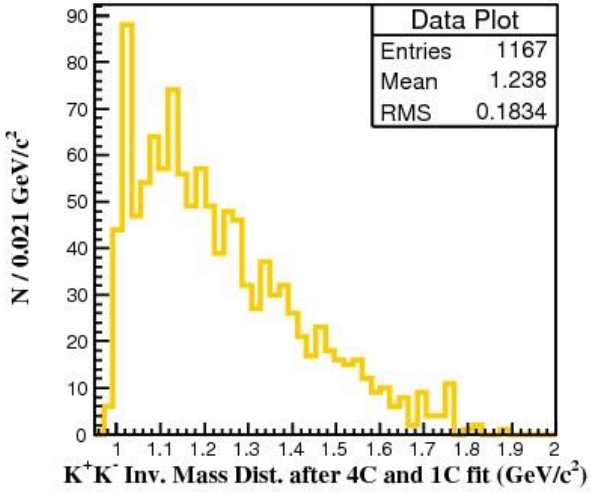




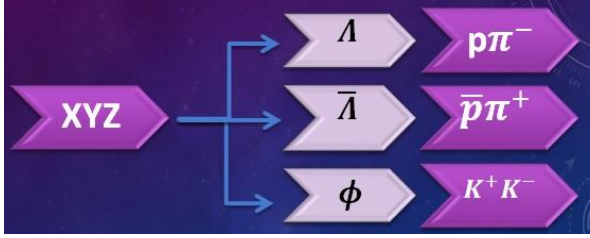


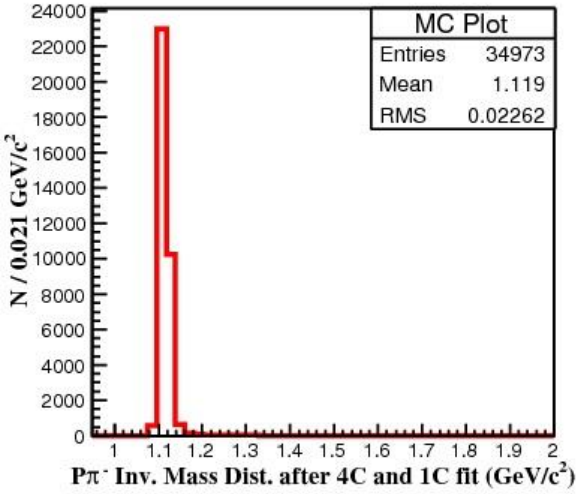


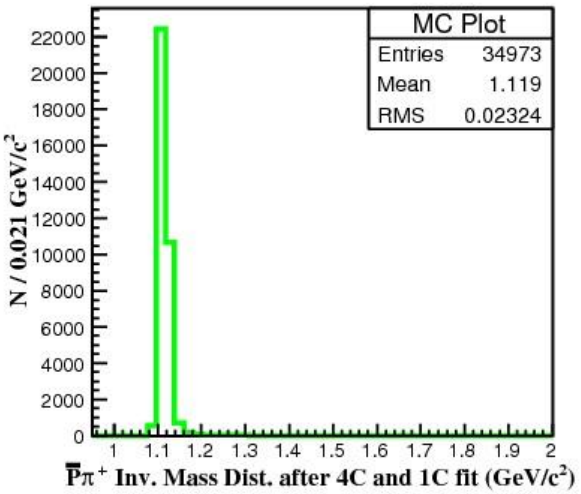


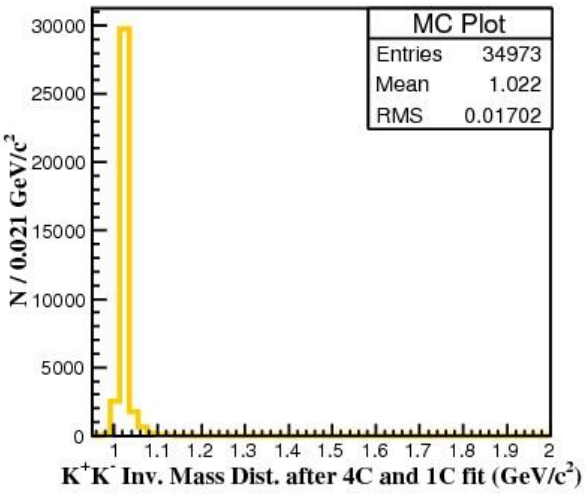


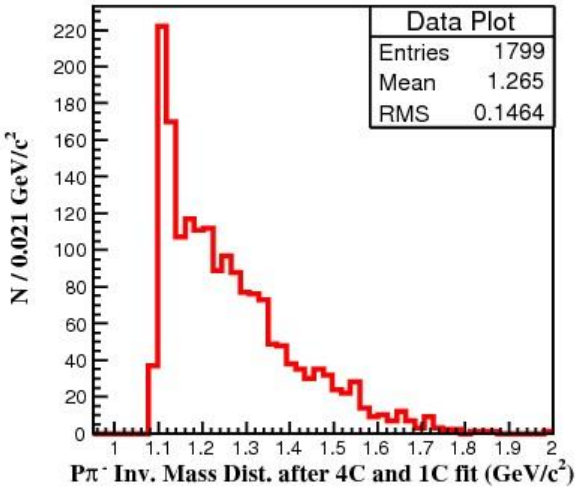
Invariant mass distribution of $p\pi^-$, $\bar{p}\pi^+$ and K^+K^- for (MC and DATA) of 4260 MEV energy after kinematic fit and without mass, χ^2_{4c} and χ^2_{1c} cuts

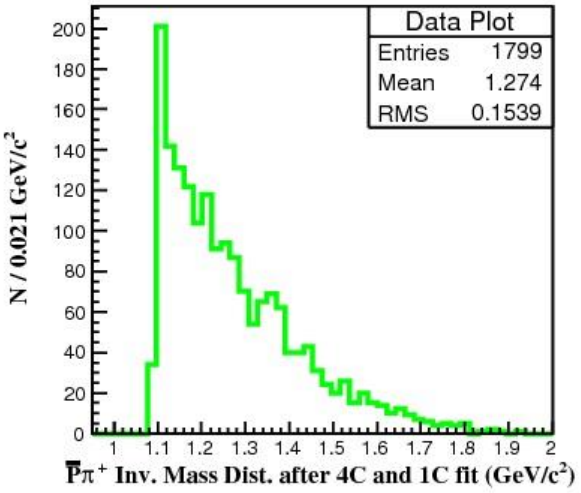


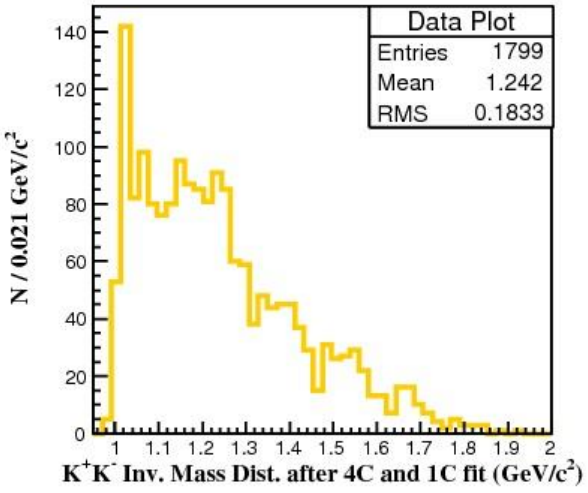




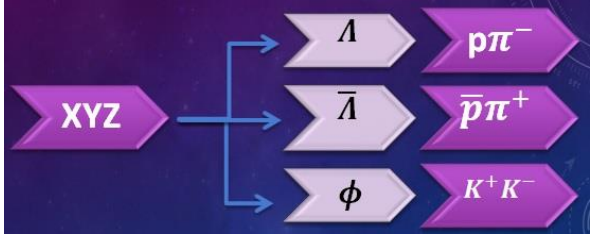


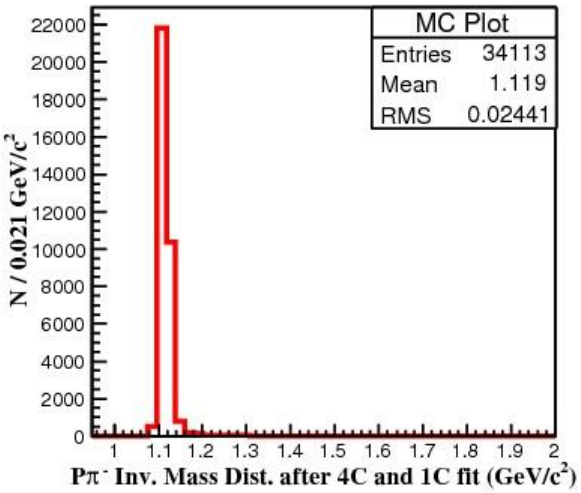


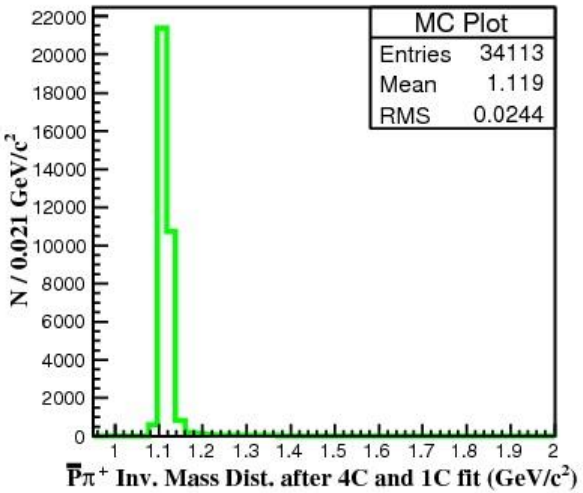


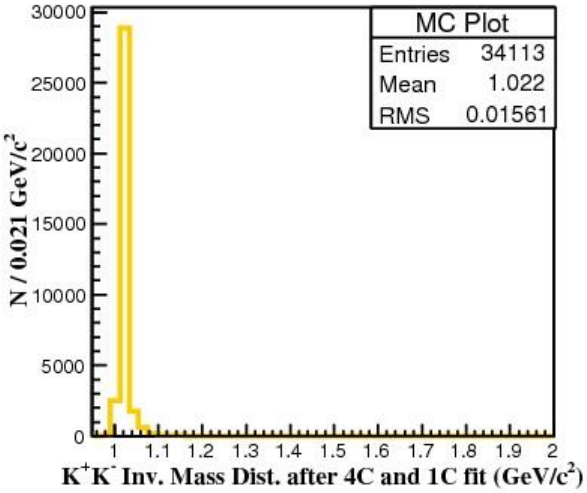


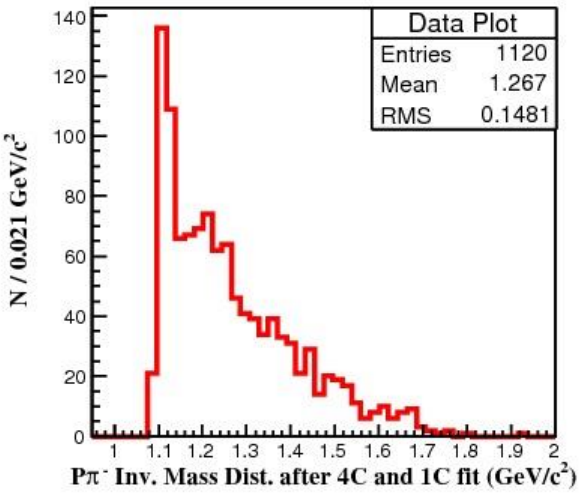
Invariant mass distribution of $p\pi^-$, $\bar{p}\pi^+$ and K^+K^- for (MC and DATA) of 4270 MEV energy after kinematic fit and without mass, χ^2_{4c} and χ^2_{1c} cuts

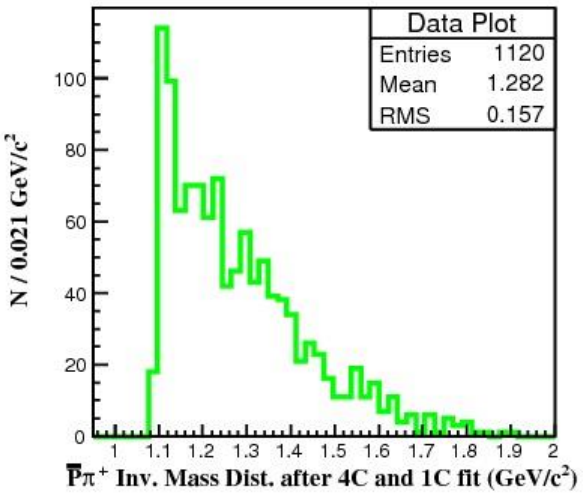


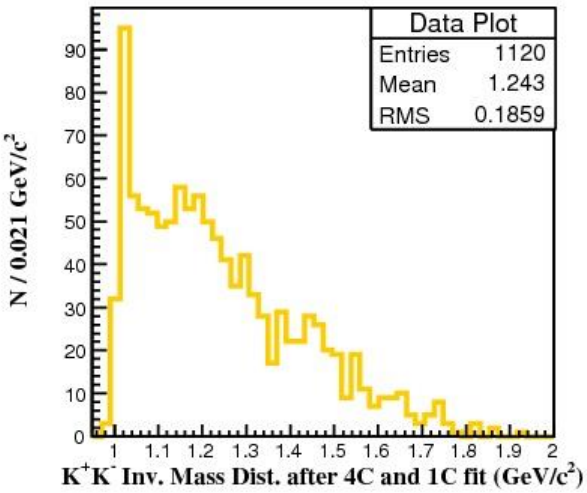




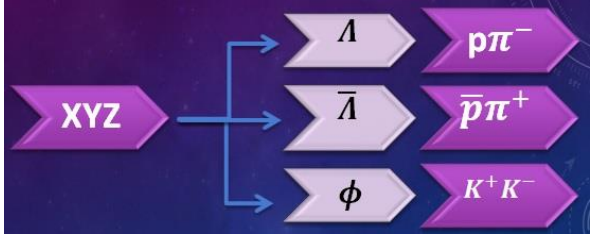


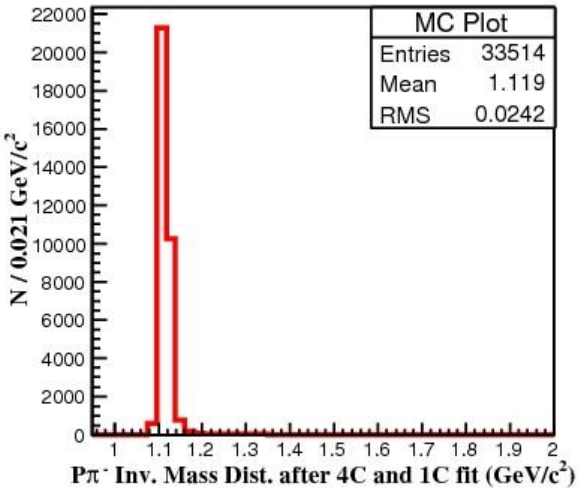


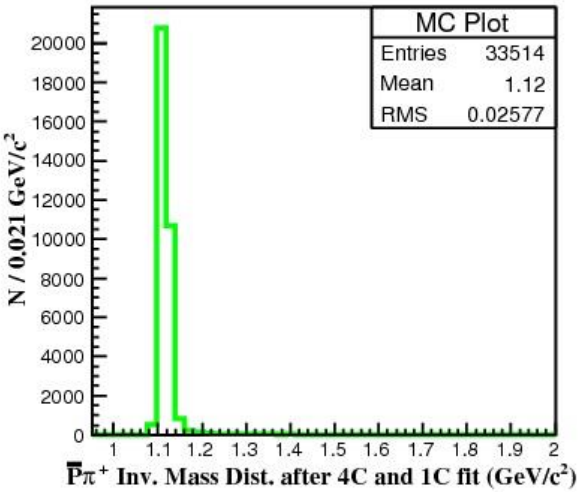


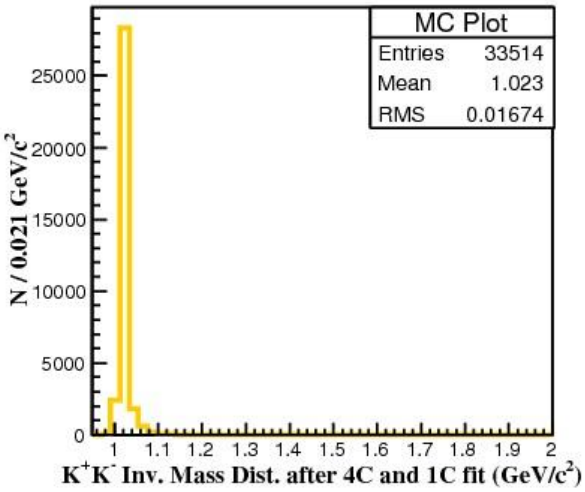


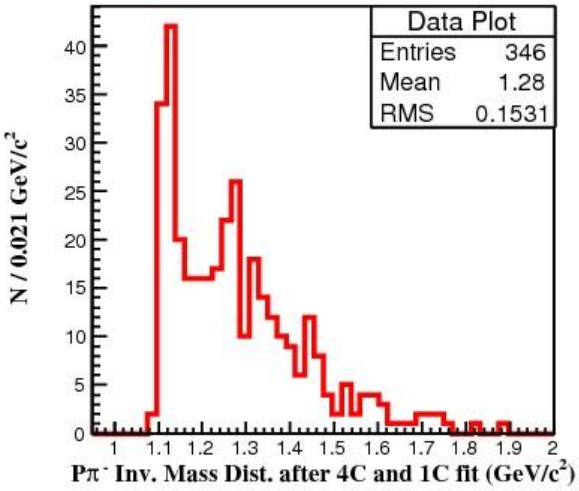
Invariant mass distribution of $p\pi^-$, $\bar{p}\pi^+$ and K^+K^- for (MC and DATA) of 4280 MEV energy after kinematic fit and without mass, χ^2_{4c} and χ^2_{1c} cuts

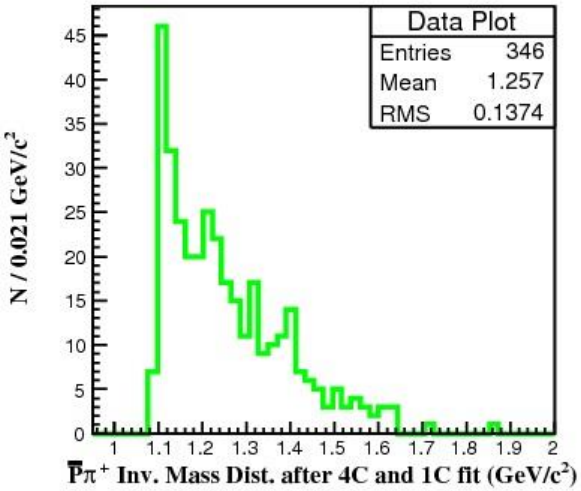


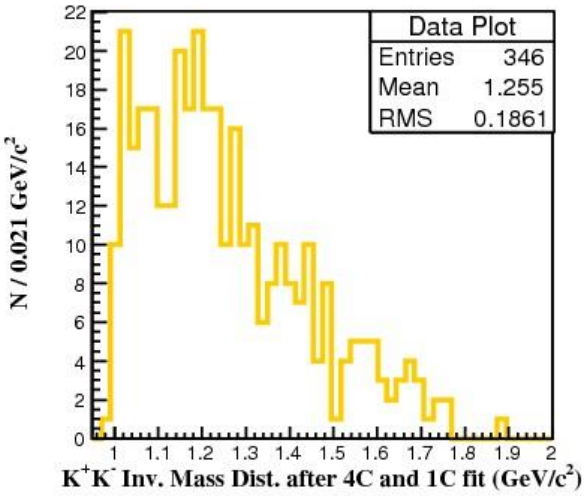


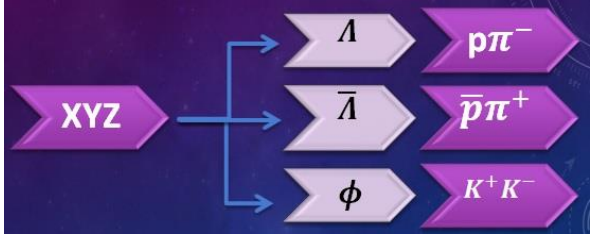




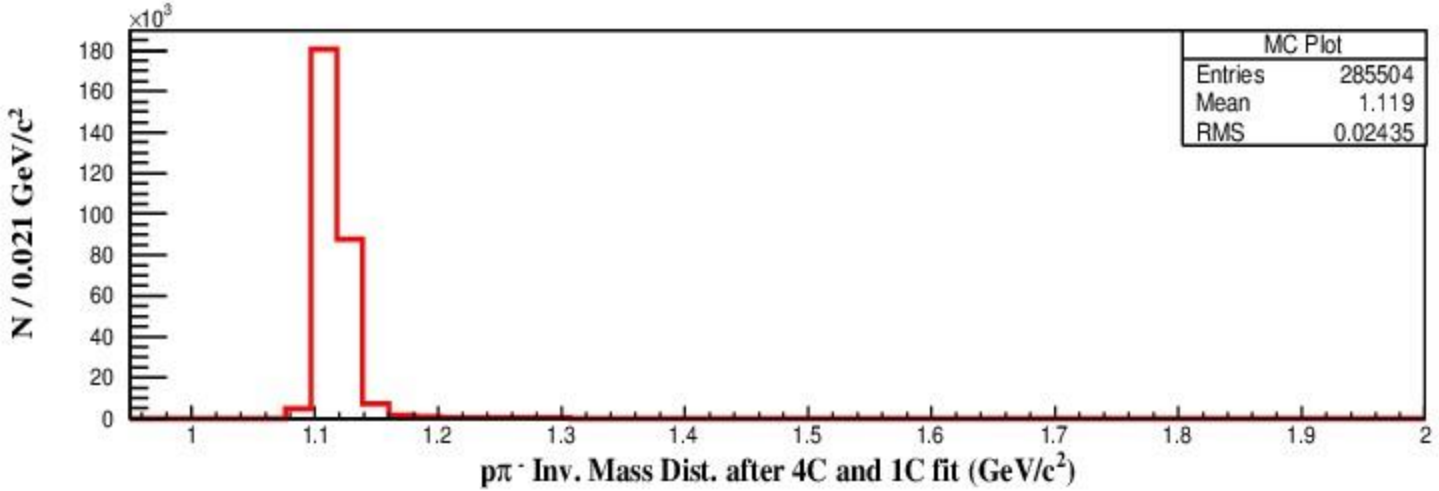


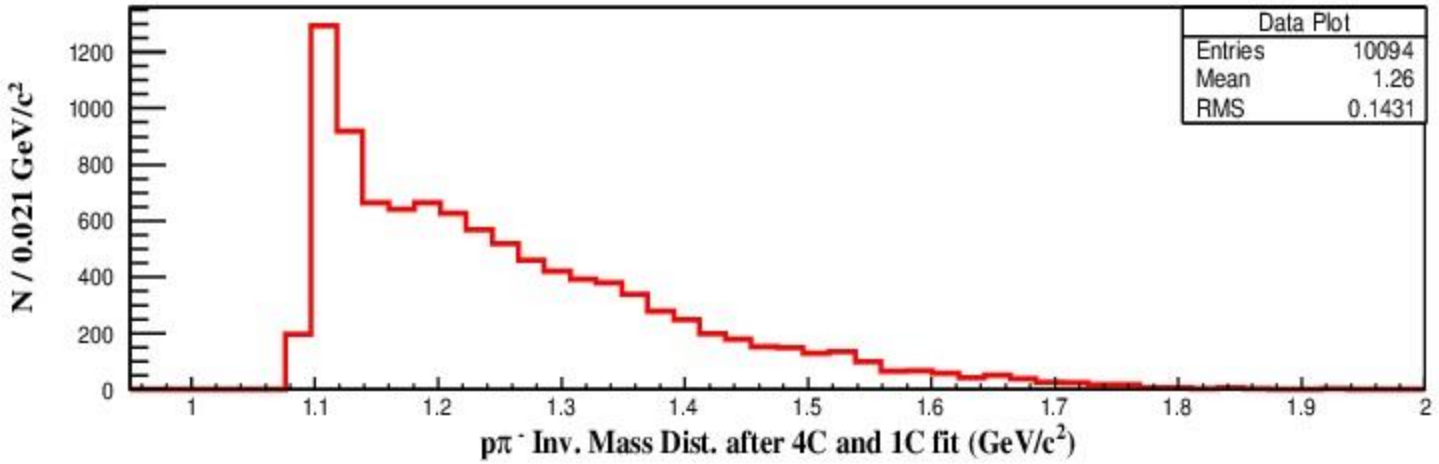


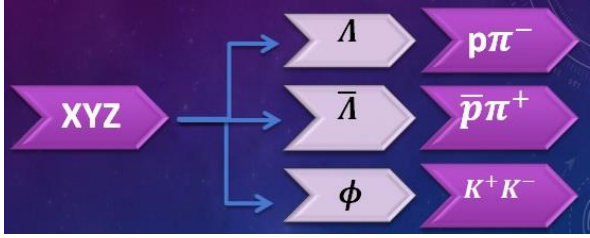




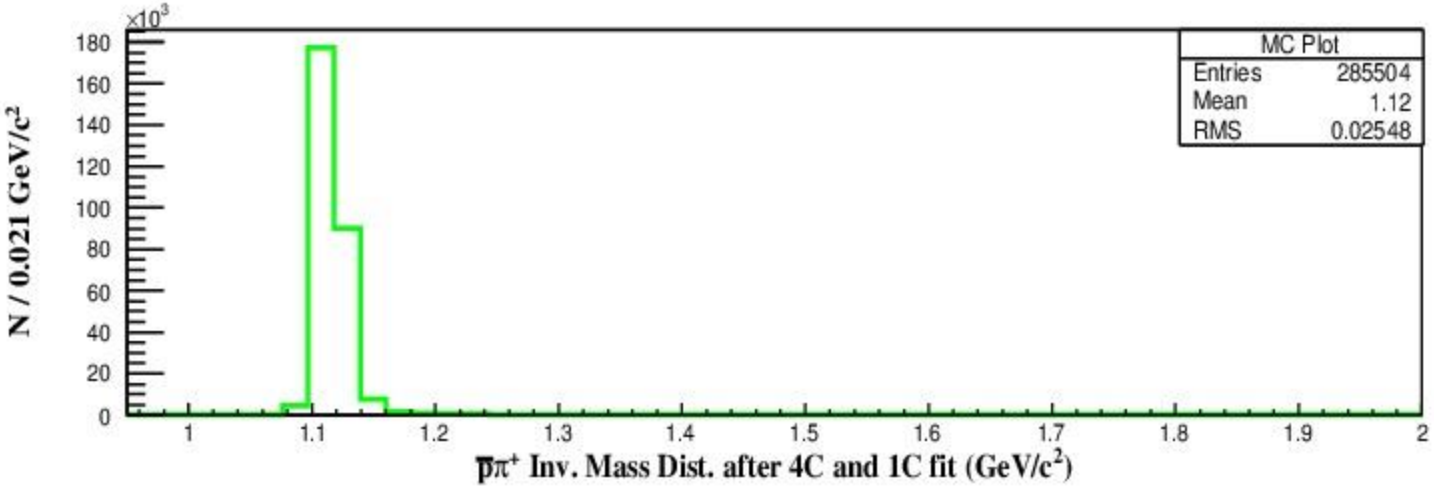
Invariant mass distribution of $p\pi^-$ (MC and DATA) of all energy points after kinematic fit and without mass, χ^2_{4c} and χ^2_{1c} cuts

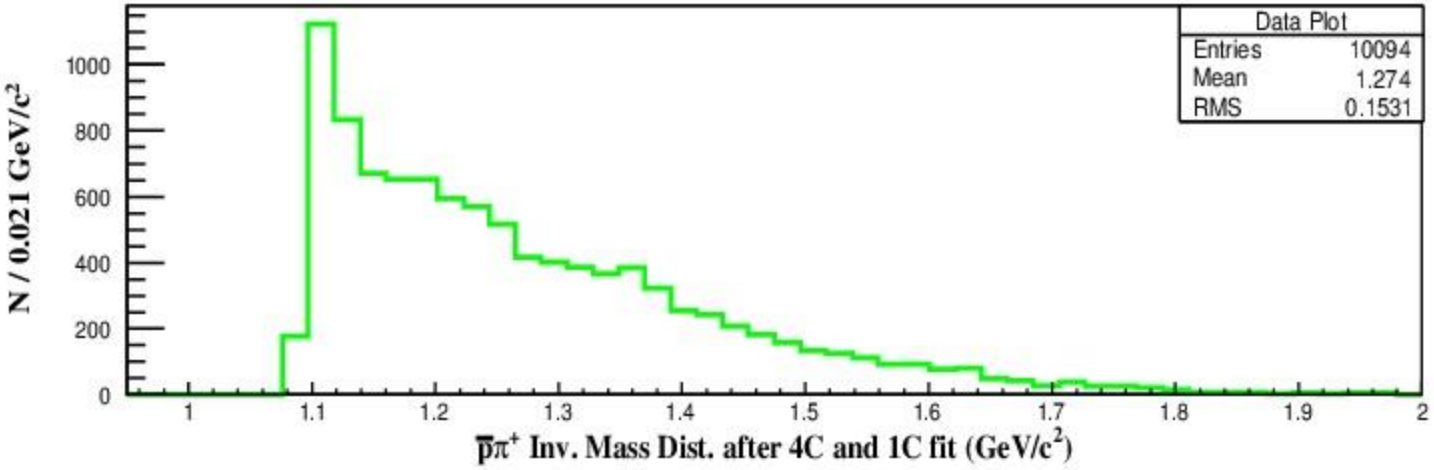


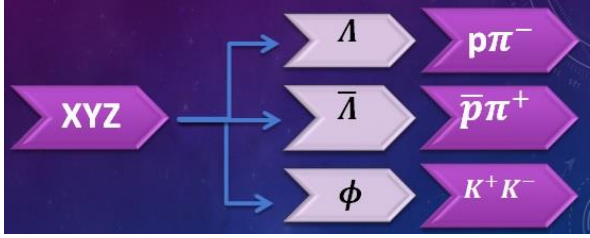




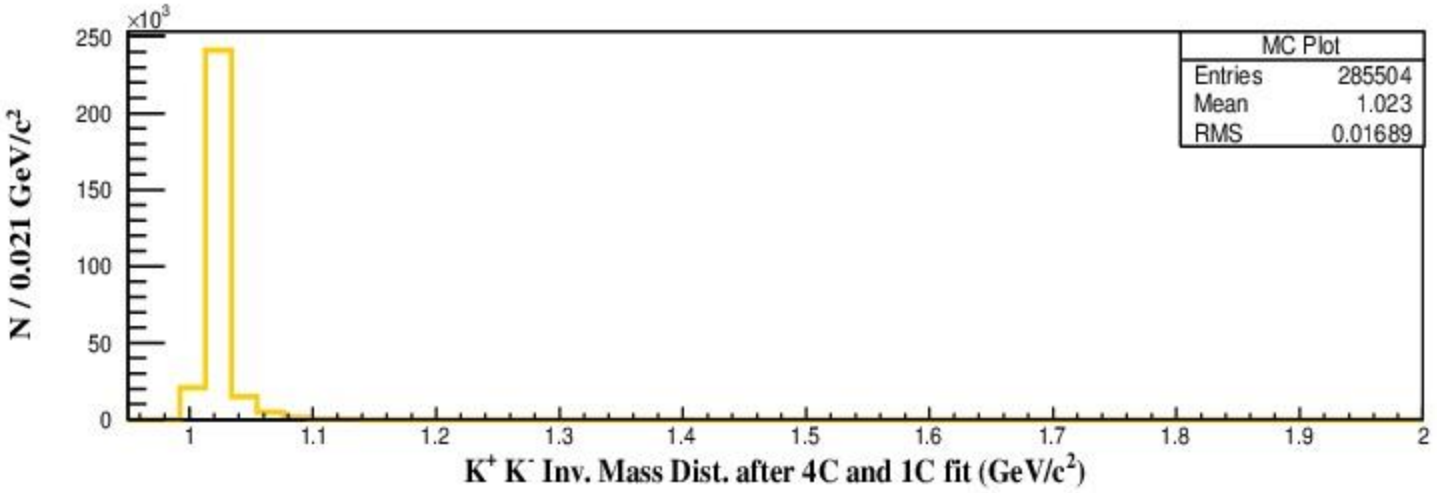
Invariant mass distribution of $\bar{p}\pi^+$ (MC and DATA) of all energy points after kinematic fit and without mass, χ^2_{4c} and χ^2_{1c} cuts

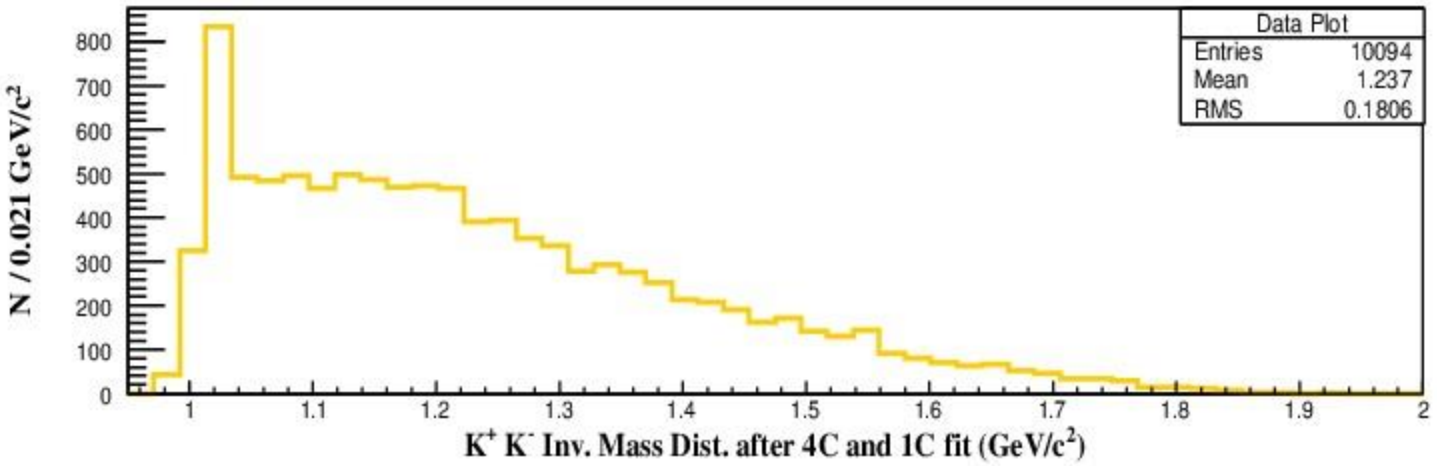




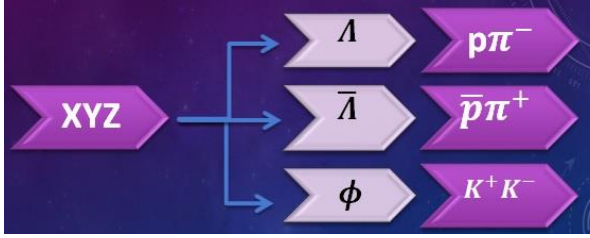


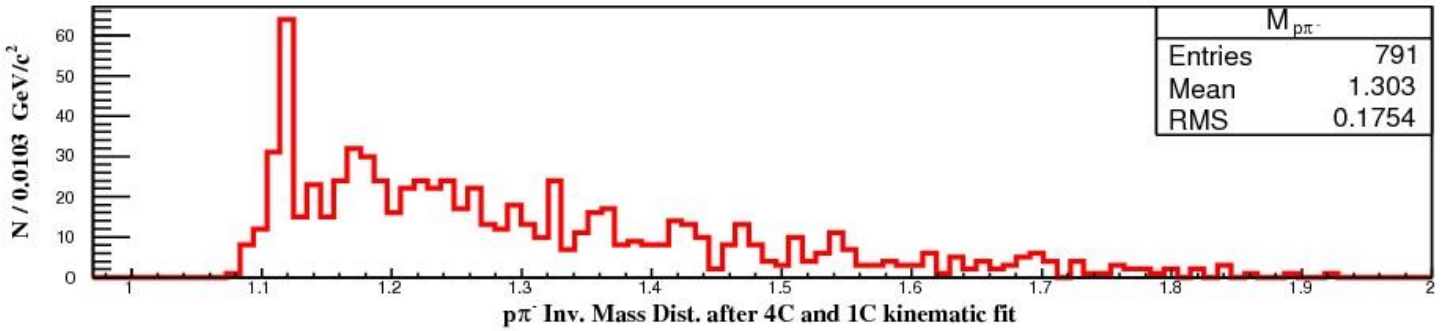
Invariant mass distribution of K^+K^- (MC and DATA) of all energy points after kinematic fit and without mass, χ^2_{4c} and χ^2_{1c} cuts

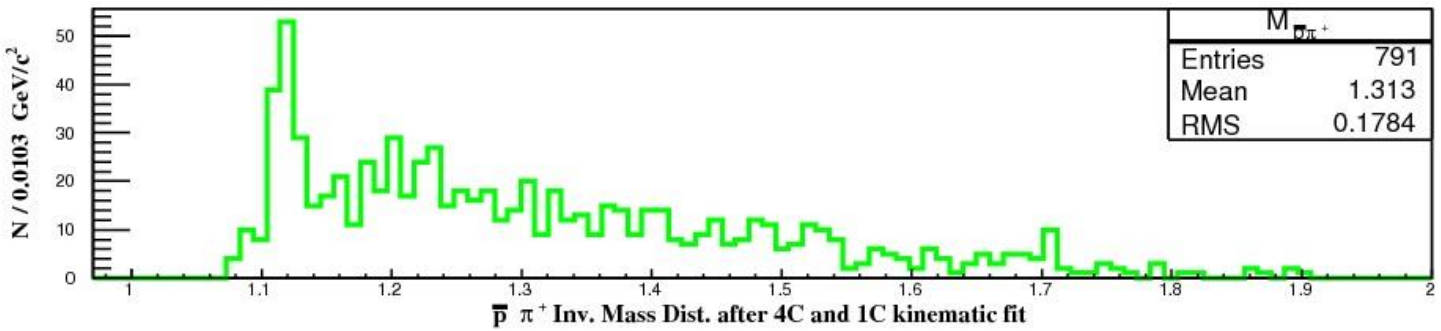


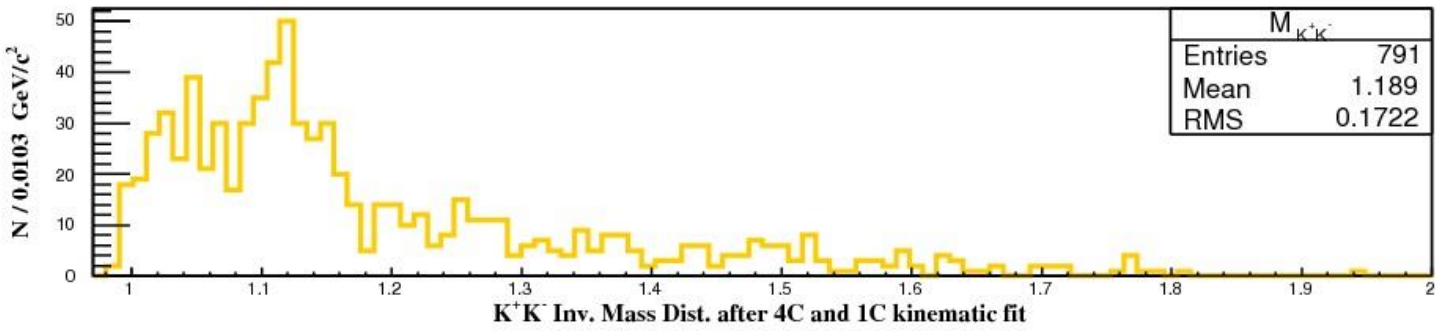


Invariant mass distribution of $p\pi^-$, $\bar{p}\pi^+$ and K^+K^- for (Inclusive MC) after kinematic fit and without mass, χ^2_{4c} and χ^2_{1c} cuts

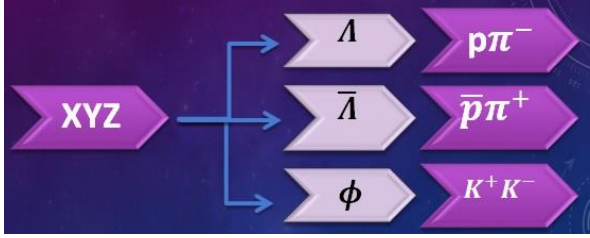


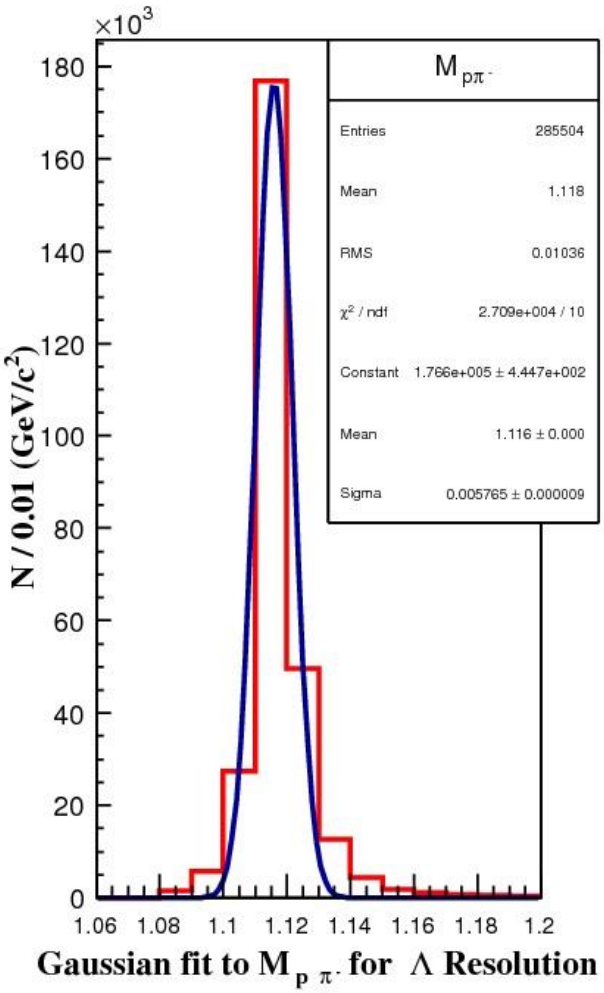


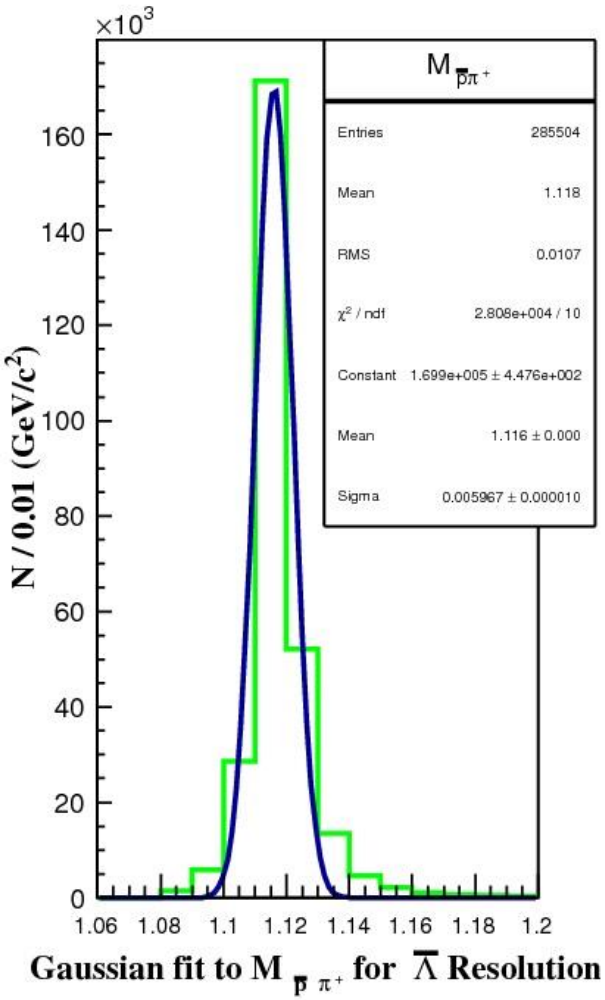


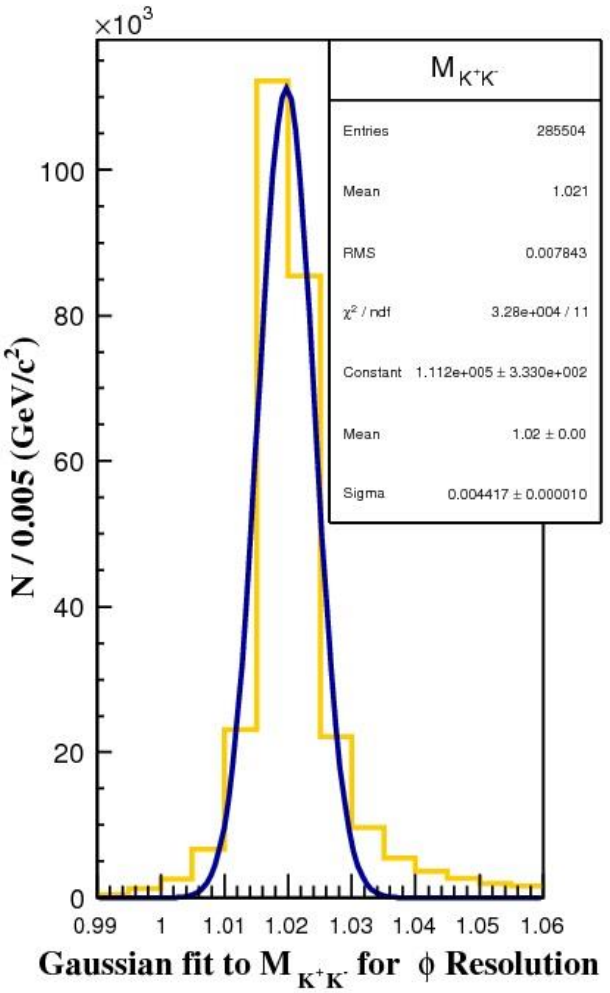


Gaussian fit to invariant mass of $M_{p\pi^-}$, $M_{\bar{p}\pi^+}$ and $M_{K^+K^-}$ for Λ, $\bar{\Lambda}$ and ϕ Resolution after 4C and 1C kinematic fit (MC)

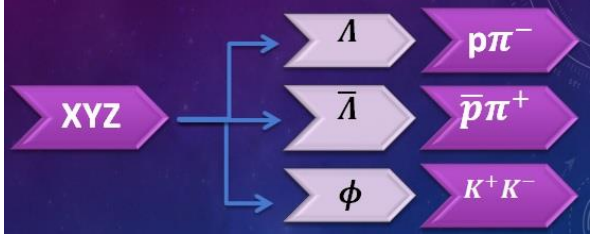


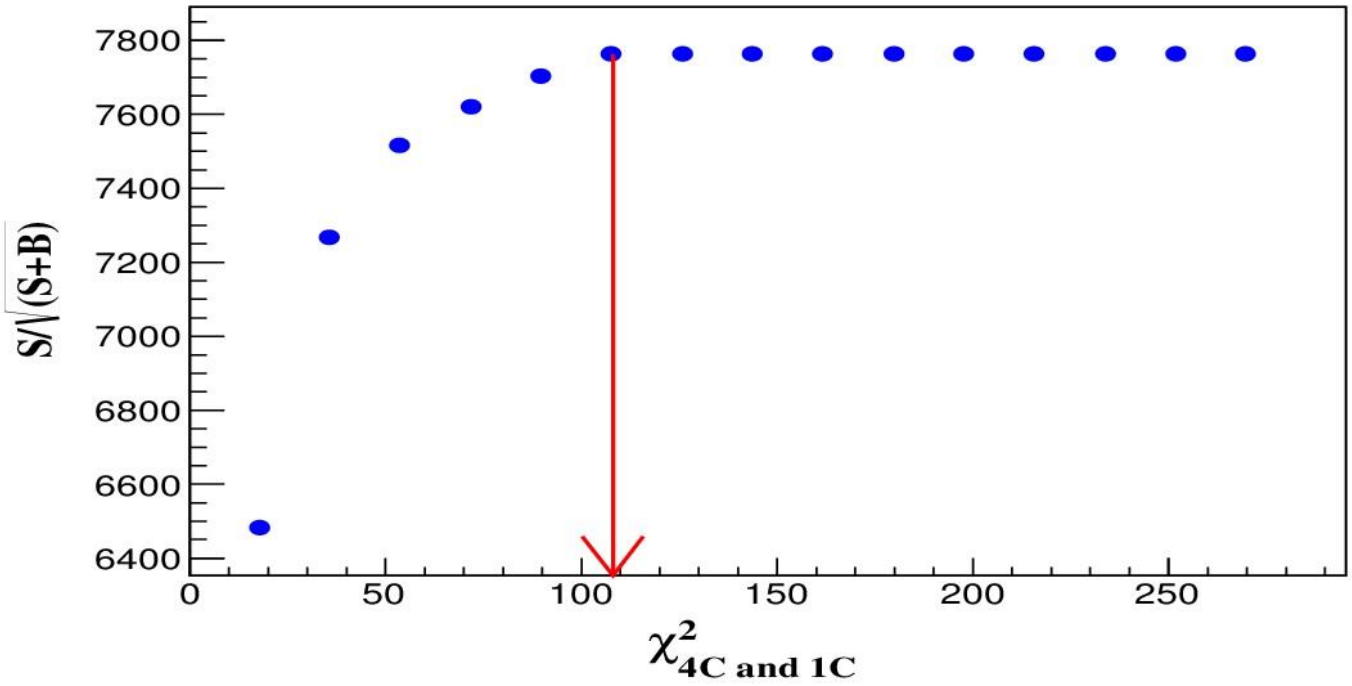




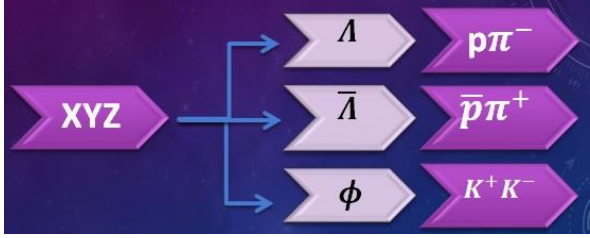


Optimization of $\chi^2_{4c\ and\ 1c}$





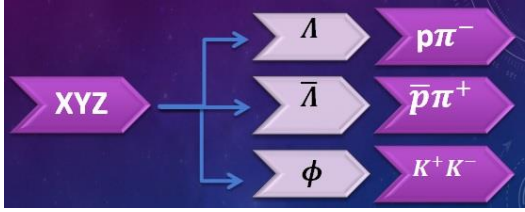
Final Event Selection



- In XYZ → ΛΛ̄ϕ study, invariant mass of K^+K^- is plotted here. To look all ΛΛ̄ϕ events, cuts have been applied (within 3σ) on ϕ by fitting the invariant mass of $p\pi^-$ and $\bar{p}\pi^+$ in MC. Fitting suggested the σ value to be 0.006GeV . To suppress the background some other cuts have also been applied including $\chi^2_{4c\ and\ 1c}$. All the cuts with their range that are applied to plot invariant mass of K^+K^- is given below.

- Following inclusive cuts of $p\pi^-$, $\bar{p}\pi^+$ and $\chi^2_{4c\ and\ 1c}$ are used:
  $|M_{p\pi^-} - M_{\Lambda}| < 0.008$,
  $|M_{\bar{p}\pi^+} - M_{\bar{\Lambda}}| < 0.008$ and
  $\chi^2_{4c\ and\ 1c} < 80$

- Following exclusive cuts of $p\pi^-K^-$, $\bar{p}\pi^+K^+$ and $p\bar{p}\pi^-\pi^+$ are used:
  $|M_{p\pi^-K^-} - M_{\Omega}| > 0.02814$,
  $|M_{\bar{p}\,\pi^+K^+} - M_{\bar{\Omega}}| > 0.02814$ and
  $|M_{p\bar{p}\,\pi^-\pi^+} - M_{J/\psi}| > 0.00777$

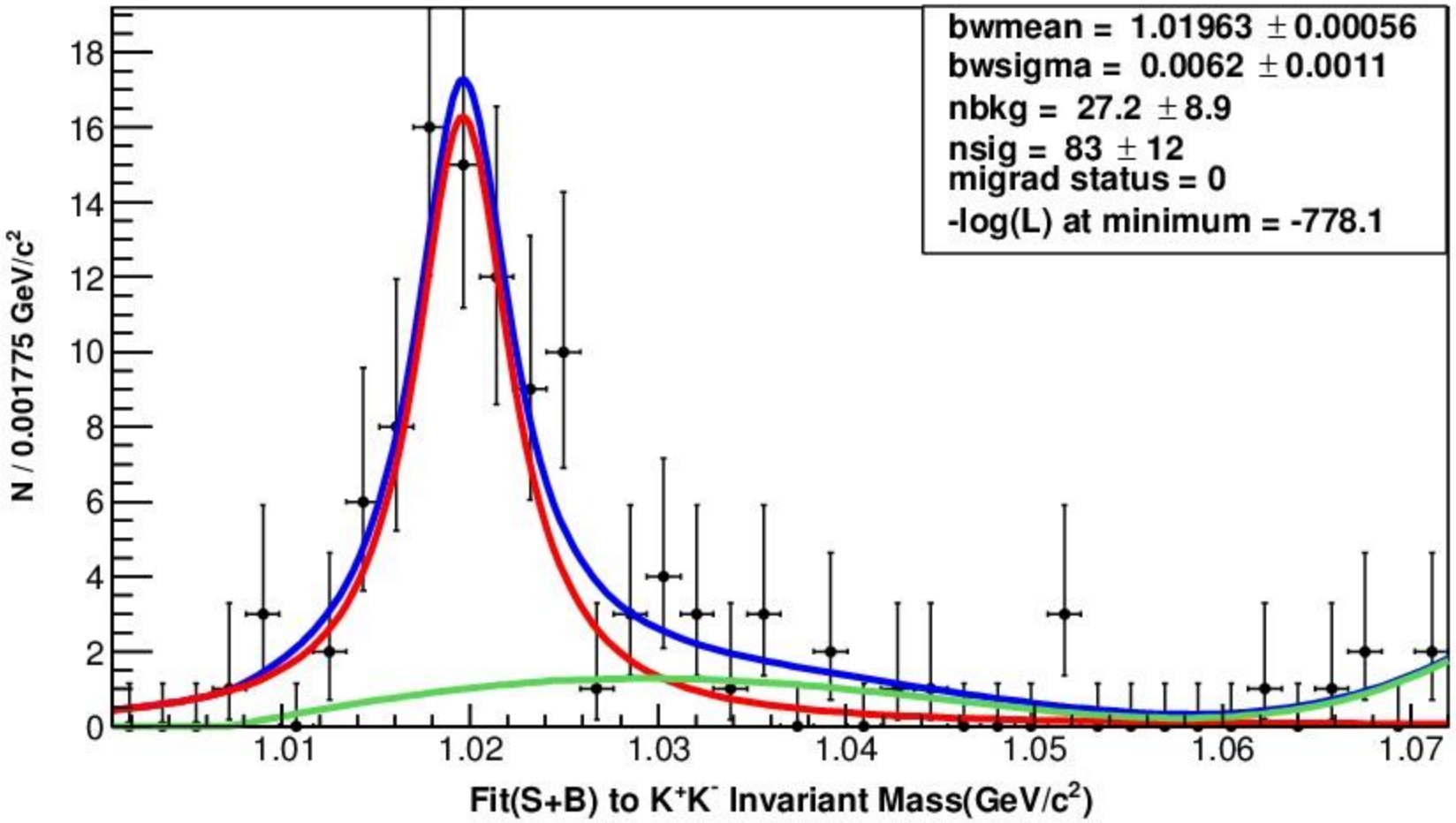


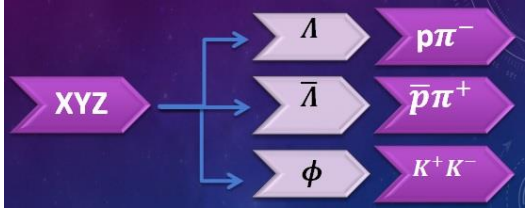
K^+K^- Invariant mass distribution of data under

$|M_{p\pi^-} - M_{\Lambda}| < 0.008$, $|M_{\bar{p}\pi^+} - M_{\bar{\Lambda}}| < 0.008$, $\chi^2_{4c\ and\ 1c} < 80$,

$|M_{p\pi^-K^-} - M_{\Omega}| > 0.02814$, $|M_{\bar{p}\,\pi^+K^+} - M_{\bar{\Omega}}| > 0.02814$ and

$|M_{p\bar{p}\,\pi^-\pi^+} - M_{J/\psi}| > 0.00777$ cuts



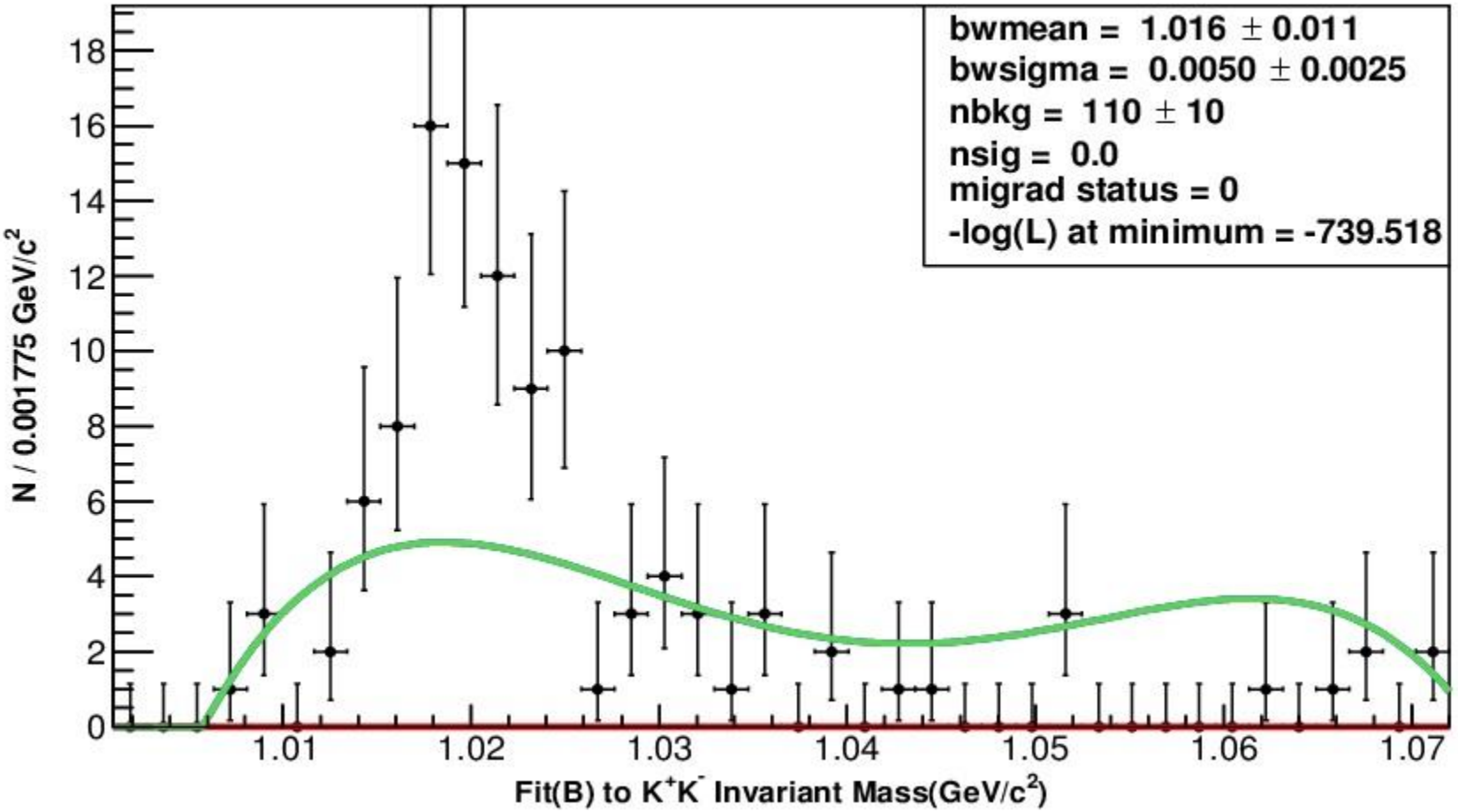


K^+K^- Invariant mass distribution of data under

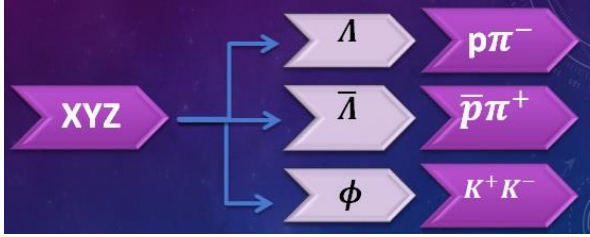
$|M_{p\pi^-} - M_{\Lambda}| < 0.008$, $|M_{\bar{p}\pi^+} - M_{\bar{\Lambda}}| < 0.008$, $\chi^2_{4c\ and\ 1c} < 80$,

$|M_{p\pi^-K^-} - M_{\Omega}| > 0.02814$, $|M_{\bar{p}\,\pi^+K^+} - M_{\bar{\Omega}}| > 0.02814$ and

$|M_{p\bar{p}\,\pi^-\pi^+} - M_{J/\psi}| > 0.00777$ cuts



Background Analysis

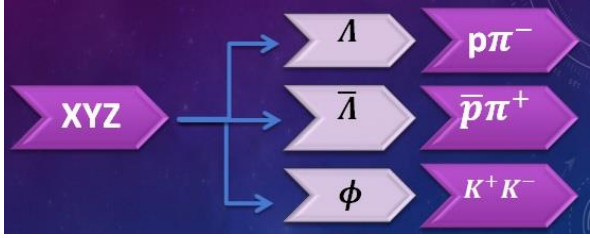


After making the final event selection of invariant mass distribution of K^+K^-, it is necessary to investigate the possible background events still affecting the signal region. For background analysis we have used 500 pb^{-1} inclusive MC data beside some exclusive MC sample generated using phase space generater. The possible background suggested by mclist is given in the table. From all the background decay channel given in table, exclusive cut of one prominent background decay channel has been applied in the final event selection.

Sr. No.	Decay Channels	$Events_{mclist}$
1	$Y(4260) \to J/\psi K^+K^-(J/\psi \to p\bar{p}\pi^+\pi^-)$	145
2	$Y(4260) \to J/\psi K^+K^-(J/\psi \to \Delta^{++}\bar{p}\pi^-)$	37
3	$Y(4260) \to J/\psi K^+K^-(J/\psi \to \Delta^{++}\Delta^{--})$	31
4	$Y(4260) \to J/\psi K^+K^-(J/\psi \to \Delta^{--}\pi^+p^+)$	31
5	$Y(4260) \to J/\psi K^+K^-(J/\psi \to \Lambda\bar{\Lambda})$	20
6	$Y(4260) \to J/\psi K^+K^-(J/\psi \to \Delta^0\bar{p}\pi^+)$	9
7	$Y(4260) \to J/\psi K^+K^-(J/\psi \to f_0' p\bar{p})$	9
8	$Y(4260) \to J/\psi K^+K^-(J/\psi \to \bar{\Delta}^0 p\pi^-)$	6
9	$Y(4260) \to J/\psi K^+K^-(J/\psi \to p\bar{p}\pi^+\pi^-\pi^0)$	4
10	$Y(4260) \to J/\psi K^+K^-(J/\psi \to \omega p\bar{p})$	4
11	$Y(4260) \to \omega\chi_{c0}(\omega \to \pi^+\pi^-, \chi_{c0} \to K^+K^-p\bar{p})$	3
12	$Y(4260) \to J/\psi K^+K^-(J/\psi \to \Delta^0\bar{\Delta}^0)$	2
13	$Y(4260) \to J/\psi\pi^+\pi^-(J\psi \to p\bar{p}f_0'')$	2
14	$Y(4260) \to \psi(2S)\pi^+\pi^-(\psi(2S) \to K^+K^-p\bar{p})$	2
15	$Y(4260) \to \omega\chi_{c0}(\omega \to \pi^+\pi^-\pi^0, \chi_{c0} \to K^+K^{*-}p\bar{p})$	2
16	$Y(4260) \to J/\psi K^+K^-(J/\psi \to \Lambda\bar{\Sigma})$	2
17	$Y(4260) \to J/\psi K^+K^-(J/\psi \to p\bar{p}\pi^+\pi^-\gamma_{FSR})$	2
18	$Y(4260) \to J/\psi K^+K^-(J/\psi \to \Sigma^{*+}\bar{\Sigma}^-)$	1
19	$Y(4260) \to J/\psi K^+K^-(J/\psi \to p\bar{p}\eta')$	1
20	$Y(4260) \to \psi(2S)\pi^+\pi^-(\psi(2S) \to p\bar{p}f_2)$	1
21	$Y(4260) \to J/\psi\pi^+\pi^-\gamma_{FSR}$	1
22	$Y(4260) \to J/\psi\pi^+\pi^-(J/\psi \to p\bar{p}K^+K^-)$	1
23	$Y(4260) \to J/\psi K^+K^-(J/\psi \to \gamma\Lambda\bar{\Lambda})$	1
24	$Y(4260) \to J/\psi\pi^+\pi^-(J/\psi \to \phi p\bar{p})$	1
25	$Y(4260) \to \pi^+\pi^-\pi^0\chi_{c2}$	1
26	$Y(4260) \to J/\psi K^+K^-(J/\psi \to p\bar{p}f_2)$	1
27	$Y(4260) \to J/\psi K^+K^-(J/\psi \to \Lambda\bar{\Lambda}\pi^0)$	1
28	$Y(4260) \to J/\psi K^+K^-(J/\psi \to p\bar{p}\rho^0)$	1
29	$Y(4260) \to J/\psi K^+K^-(J/\psi \to \Delta^{++}\Delta^{--}\pi^0)$	1
30	$Y(4260) \to \pi^+\pi^-\pi^0\chi_{c1}$	1

The possible background for $\Lambda\bar{\Lambda}\phi$

Detection Efficiency

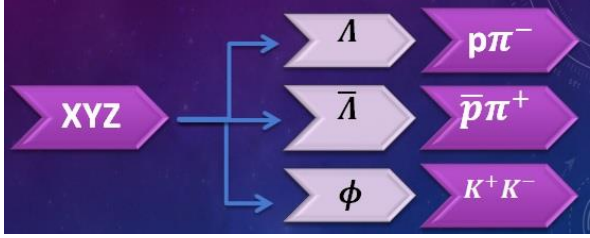


- In order to check the detection efficiency of a detector, a signal MC root file is generated using phase space (PHSP) generator. The detector was able to detect 285,504 events out of 900,000.
- Percentage of detection efficiency = $\frac{N_{MC}(detected)}{N_{MC}(total)}$ x 100

  = $\frac{285{,}504}{900{,}000}$ x 100

  = 31.7226 %
- Where $N_{MC}(detected)$ and $N_{MC}(total)$ is the number of signal monte carlo events detected and total number of signal monte carlo events generated using phase space (PHSP) generator respectively.

Cross section Calculation of XYZ→ $\Lambda\bar{\Lambda}\phi$



Using the data of $4580.1\,pb^{-1}$ integrated luminosity, 83 ± 12 clear signals of $XYZ \to \Lambda\bar{\Lambda}\phi$ with some background has seen. Calculation of cross section (σ) is discussed below.

$$\sigma\,(XYZ \to \Lambda\bar{\Lambda}\phi) = \frac{N_{\phi}^{obs}}{\mathcal{L}_{int} \times \mathcal{B}(\Lambda \to p\pi^-) \times \mathcal{B}(\bar{\Lambda} \to \bar{p}\pi^+) \times \mathcal{B}(\phi \to K^+K^-) \times \epsilon}$$

$$= \frac{83}{4580.1\,pb^{-1} \times 0.639 \times 0.639 \times 0.489 \times 0.317226}$$

$$= 0.2861039 \times 10^{-12}\,b$$

$$= 286.10\,fb$$

Formula of cross section deduced the cross section (σ) to be $286.10\,fb$, where N_{ϕ}^{obs} is the number of observed signal of ϕ, $\mathcal{L}_{int}$ shows the data of integrated luminosity, $\mathcal{B}(\Lambda \to p\pi^-)$ is the branching fraction of $\Lambda \to p\pi^-$, $\mathcal{B}(\bar{\Lambda} \to \bar{p}\pi^+)$ is the branching fraction of $\bar{\Lambda} \to \bar{p}\pi^+$, $\mathcal{B}(\phi \to K^+K^-)$ is the branching fraction of $\phi \to K^+K^-$ and ϵ is the value of detection efficiency of the detector. Values of branching fractions $\mathcal{B}(\Lambda \to p\pi^-)$, $\mathcal{B}(\bar{\Lambda} \to \bar{p}\pi^+)$ and $\mathcal{B}(\phi \to K^+K^-)$ are taken from particle data group (PDG) 2016.

Systematic Uncertainty Estimation

Sr. No.	Sources of uncertainty in $\sigma(XYZ \to \Lambda\Lambda\phi)$	Systematic uncertainty (%)
1	Luminosity	1.0
2	Statistical error	0.4366
3	MC Model	4.4584
4	$\mathcal{B}(\Lambda \to p\pi^-)$	0.7825
5	$\mathcal{B}(\bar{\Lambda} \to \bar{p}\pi^+)$	0.7825
6	$\mathcal{B}(\phi \to K^+K^-)$	1.0225
7	PID	6
8	Track identification	12
	Total uncertainty	14.2596

Summary of the systematic percentage uncertainties for cross section measurement of XYZ data sample.

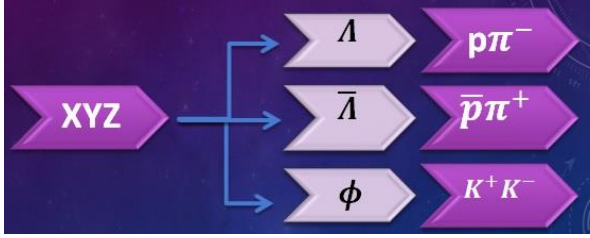
Statistical significance of ϕ signal

$$S = \sqrt{|2\,ln L_{max}(S+B) - 2\,ln L_{max}(B)|}$$

$$= \sqrt{|-778.1 - (-739.518)|}$$

$$= 6.21$$

Summary and Analysis Results



Analysis is performed using the data sets collected at center of mass energies $\sqrt{s}$ = 4190, 4200, 4210, 4220, 4237, 4246, 4260, 4270 and 4280 MeV with the BESIII detector and BEPCII collider. The decay channel XYZ $\rightarrow \Lambda\bar{\Lambda}\phi$ is studied for the very first time to measure the cross section. Real data of $4580.1\,pb^{-1}$ is used to check the number of events producing $\Lambda\bar{\Lambda}\phi$, for which we have used inclusive MC of $500\,pb^{-1}$ beside some exclusive MC sample generated using phase space generater to remove the background. Based on data of $4580.1\,pb^{-1}$, cross section of XYZ $\rightarrow \Lambda\bar{\Lambda}\phi$ is measured to be 286.10 $\pm$40.796($syst$) $\pm$43.716($stat$) fb where the first error is systematic and the second is statistical. For convenience analysis result is also given in table .

Center of mass energy $\sqrt{s}$ (GeV)	Reconstruction of $\Lambda\bar{\Lambda}\phi$	Cross section σ (fb)
4.190, 4.200, 4.210, 4.220, 4.237, 4.246, 4.260, 4.270 and 4.280	$\Lambda \rightarrow p\pi^-$, $\bar{\Lambda} \rightarrow \bar{p}\pi^+$, $\phi \rightarrow K^+K^-$	286.10 $\pm$40.796($syst$) $\pm$43.716($stat$)

Analysis result


Thankyou