Study of $e^+e^- \to K_S^0 K^\pm \pi^\mp$

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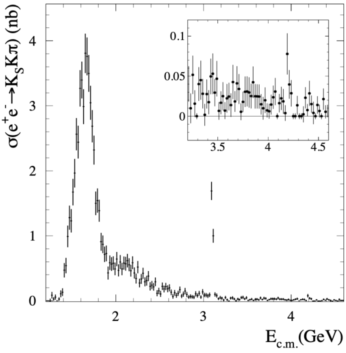
Content

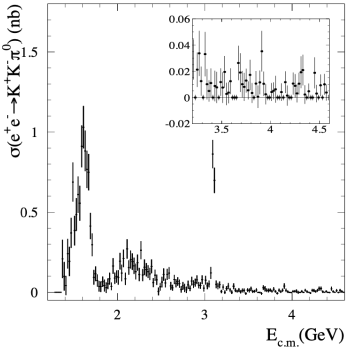
- Motivation
- Data Sets
- Event Selection
- Background Study
- Signal Yeilds
- Summary and Next to do

Motivation

- Cross section of $e^+e^- \to KK\pi$ such as $K^+K^-\pi^0$, $K_S^0K^\pm\pi^\mp$ and $\phi\pi^0$ are measured by Babar through ISR return method.



(a) $e^+e^- \to K_S^0K^\pm\pi^\mp$



(b) $e^+e^- \to K^+K^-\pi^0$

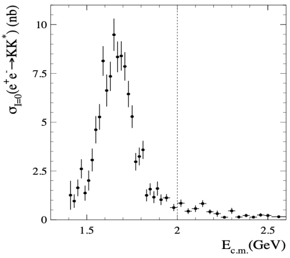
Figure: Measurement of $e^+e^- \to KK\pi$ from Babar Phys. Rev. D 77, 092002

Motivation

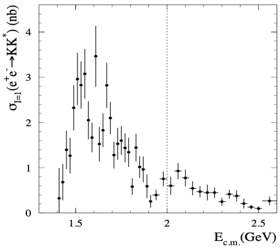
- Babar use Dalitz analysis method to study $K_S^0 K^\pm \pi^\mp$ and $K^+ K^- \pi^0$ channel at c.m. energies below 3.1 GeV.
- The main contribution of intermediate states comes from $KK^*(892)$ and $KK_2^*(1430)$
- Difference between $K_S^0 K^\pm \pi^\mp$ and $K^+ K^- \pi^0$ channel
  - The final state $K^+ K^- \pi^0$ can be produced through $K^{*\pm}(892) K^\mp$ and $K_2^{*\pm}(1430) K^\mp$
  - The final state $K_S^0 K^\pm \pi^\mp$ can be produced through both charged $K^{*\pm} K$ and neutral $K^{*0} K_S^0$
- KK^* mode have isospin 0 and 1, $K_S^0 K^\pm \pi^\mp$ final state have charged and neutral channel. We can separately extract the isoscale and isovector components.

Motivation

- From Babar's Dalitz plot analysis of $e^+e^- \to K^*(892)K$



(a) I=0

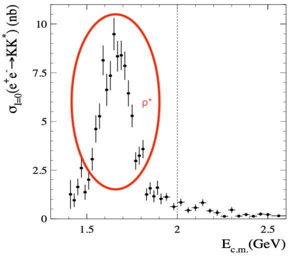


(b) I=1

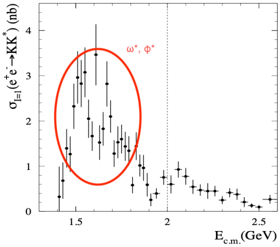
Figure: Isoscalar and isovector components of the cross section for the process $e^+e^- \to K^*(892)K$ from Babar

Motivation

- Resonance around 2 GeV: $\rho(2000)$, $\rho(2150)$, $\phi(2170)$
- The production of ρ^* is higher, even $\rho^* \to K^* K$ is suppressed by OZI rule.



(a) I=0



(b) I=1

Figure: Isoscalar and isovector components of the cross section for the process $e^+e^- \to K^*(892)K$ from Babar

- $e^+e^-(1^{--})$ experiment(direct production) is cleaner.

Data Sets

- Boss version: 665p01
- Data: 2015 R scan data

E_{cms}	$\mathcal{L}(pb^{-1})$	run number
2.0000	10.1 ± 0.1	$41729 \sim 41909$
2.0500	3.34 ± 0.03	$41911 \sim 41958$
2.1000	12.2 ± 0.1	$41588 \sim 41727$
2.1250	108 ± 1	$42004 \sim 43253$
2.1500	2.84 ± 0.02	$41533 \sim 41579$
2.1750	10.6 ± 0.1	$41416 \sim 41532$
2.2000	13.7 ± 0.1	$40989 \sim 41121$
2.2324	11.9 ± 0.1	$41122 \sim 41239$
2.3094	21.1 ± 0.1	$41240 \sim 41411$
2.3864	22.5 ± 0.2	$40806 \sim 40951$
2.6444	33.7 ± 0.2	$40128 \sim 40296$
2.6464	34.0 ± 0.3	$40300 \sim 40435$

Data Sets

- Signal MC: 10M PHSP MC without ISR generated by BesEvtGen

Process	Generator
$e^+e^- \to K_S^0 K^\pm \pi^\mp$	PHSP
$K_S^0 \to \pi^+\pi^-$	PHSP

- Inclusive MC: 4.95M $q\bar{q}$ MC at 2.125 GeV

Event Selection

- Signal: $e^+e^- \to K_S^0 K^\pm \pi^\mp \to (\pi^+\pi^-) K^\pm \pi^\mp$

Charged Tracks

- $N_{charged} = 4$
- $N_+ = N_-, Q_{total} = 0$
- 4 charged tracks are considered as pions.

K_S^0 reconstruction

- Loop all charged tracks. Select smallest χ^2 combination of $\pi^+\pi^-$ as the K_S^0 candidate.
- $L/\delta L > 2$

Charged Selection

- $|cos\theta| < 0.93$
- $V_{xy} < 1\ cm, V_z < 10\ cm$

PID For Left 2 Charged Tracks

- $\pi : p(\pi) > p(K)$
- $K : p(K) > p(\pi)$
- $N_\pi = N_K = 1$

Vertex Fit

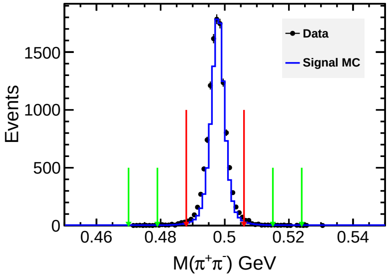
- Vertex fit for $K^\pm \pi^\mp$
- Second vertex fit for K_S^0

Kinematic Fit

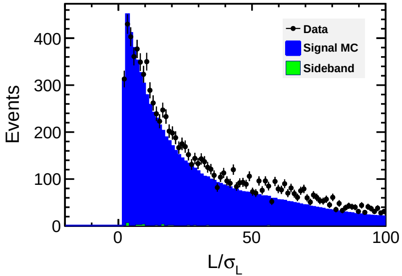
- 4C for $K_S^0 K^\pm \pi^\mp$

Event Selection

- K_S^0 candidates



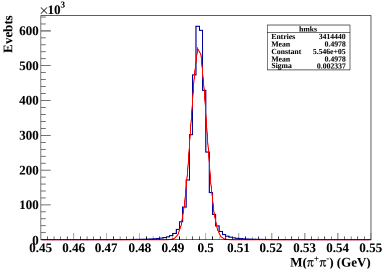
(a) K_S^0 reconstruction



(b) Decay length

Event Selection

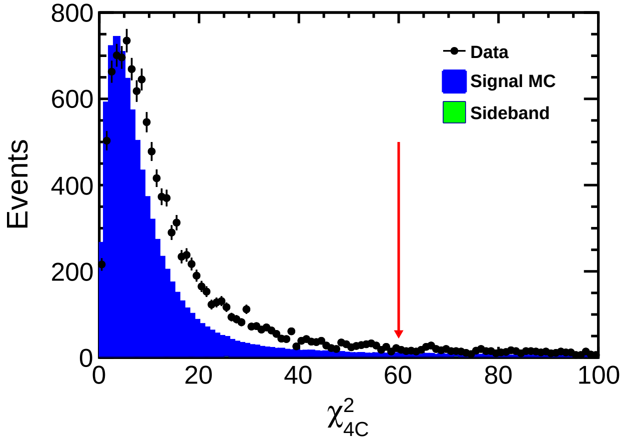
- K_S^0 resolution



(c) K_S^0 resolution

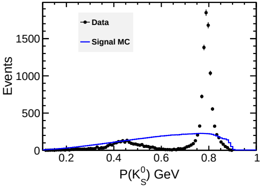
Event Selection

- χ^2 distribution of kinematic fit

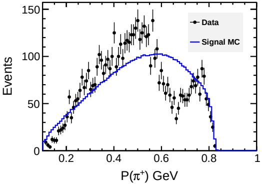


Event Selection

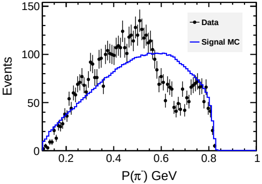
- Momentum distribution at 2.125 GeV



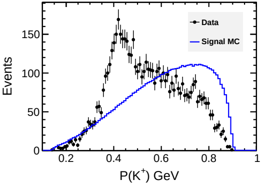
(a) K_S^0 momentum



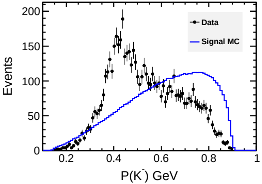
(b) π^+ momentum



(c) π^- momentum



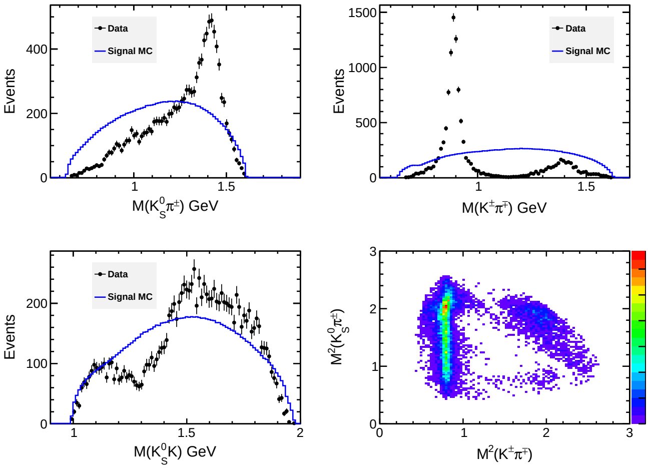
(d) K^+ momentum



(e) K^- momentum

Event Selection

- Mass distribution and Dalitz plot at 2.125 GeV

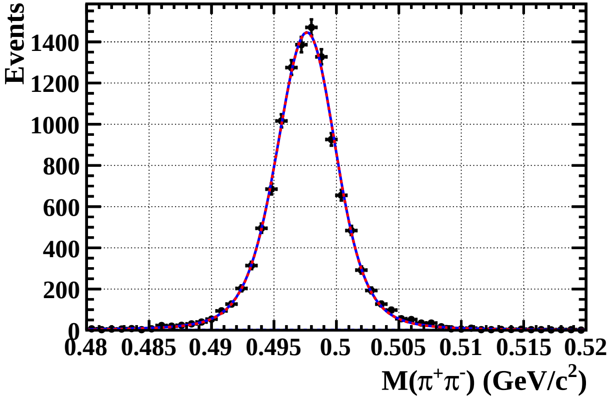


Background Study

- Inclusive MC sample after event selection

decay tree	nEtr	nCEtr
$e^+e^- \to K_S^0 K^+ \pi^-, K_S^0 \to \pi^+\pi^-$	5625	5625
$e^+e^- \to K_S^0 K^- \pi^+, K_S^0 \to \pi^+\pi^-$	5583	11208
$e^+e^- \to \gamma\gamma^*, \gamma^* \to K_S^0 K^+ \pi^-, K_S^0 \to \pi^+\pi^-$	1387	12595
$e^+e^- \to \gamma\gamma^*, \gamma^* \to K_S^0 K^- \pi^+, K_S^0 \to \pi^+\pi^-$	1358	13953
$e^+e^- \to \gamma\gamma^*, \gamma^* \to K^0 K^+ \pi^-, K^0 \to K_S^0, K_S^0 \to \pi^+\pi^-$	717	14670
$e^+e^- \to \gamma\gamma^*, \gamma^* \to K^0 K^- \pi^+, K^0 \to K_S^0, K_S^0 \to \pi^+\pi^-$	687	15357
$e^+e^- \to \gamma\gamma^*, \gamma^* \to \pi^- a_2^+, a_2^+ \to K^0 K^+, K^0 \to K_S^0, K_S^0 \to \pi^+\pi^-$	6	15363
$e^+e^- \to \gamma\gamma^*, \gamma^* \to \pi^+ a_2^-, a_2^- \to K^0 K^-, K^0 \to K_S^0, K_S^0 \to \pi^+\pi^-$	4	15367

Signal Yeilds

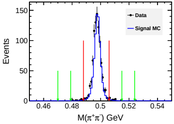


- Signal: MC shape $\otimes$ Gaussian function
- Background: 1st order polynomial

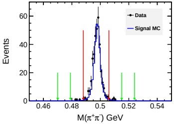
$$N_{signal} = 11592.2 \pm 110.4,\ N_{bkg} = 59.0 \pm 25.6$$

Ks at other energy points

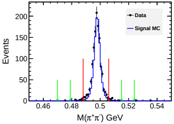
- Ks at other energy points



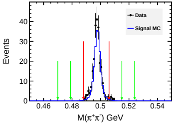
(a) 2.00 GeV



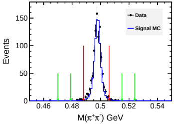
(b) 2.05 GeV



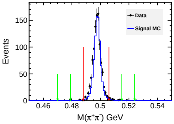
(c) 2.10 GeV



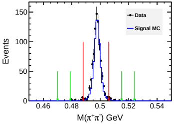
(d) 2.15 GeV



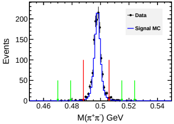
(e) 2.175 GeV



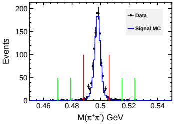
(f) 2.20 GeV



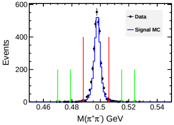
(g) 2.2324 GeV



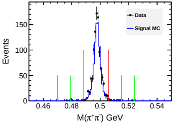
(h) 2.3094 GeV



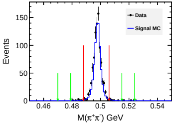
(i) 2.3864 GeV



(j) 2.396 GeV



(k) 2.6444 GeV

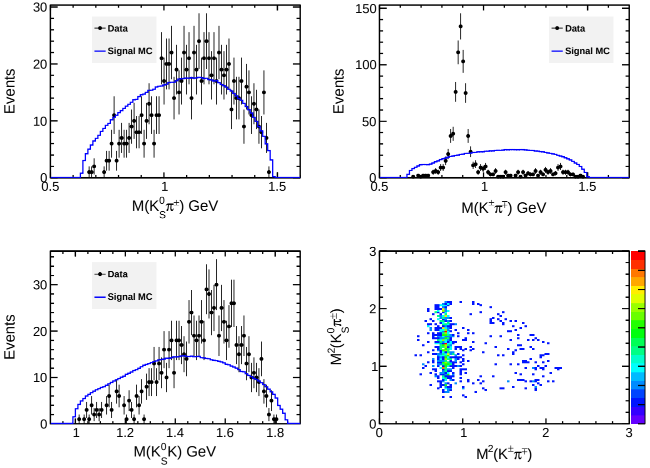


(l) 2.6464 GeV

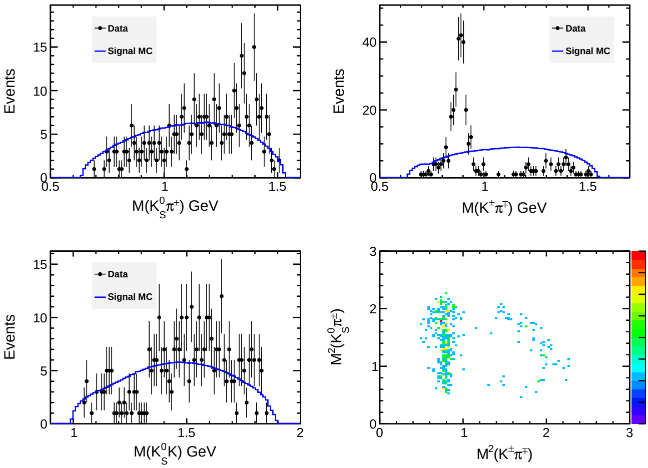
Events at other energy points

E_{cms} GeV	$\mathcal{L}$ pb^{-1}	N_{signal}	N_{bkg}	N_{bkg}/N_{signal}
2.0000	10.1 ± 0.1	921.5 ± 30.9	3.5 ± 3.3	0.37%
2.0500	3.34 ± 0.03	349.1 ± 19.1	3.9 ± 3.4	1.12%
2.1000	12.2 ± 0.1	1263.8 ± 37.4	17.2 ± 12.2	1.36%
2.1500	2.84 ± 0.02	232.0 ± 15.2	6.0 ± 3.2	2.59%
2.1750	10.6 ± 0.1	959.8 ± 31.9	7.3 ± 3.5	0.76%
2.2000	13.7 ± 0.1	1026.9 ± 60.5	2.3 ± 1.1	0.22%
2.2324	11.9 ± 0.1	892.0 ± 30.7	8.0 ± 5.3	0.89%
2.3094	21.1 ± 0.1	1399.3 ± 37.8	3.5 ± 2.1	0.25%
2.3864	22.5 ± 0.2	1184.7 ± 35.7	17.3 ± 10.2	1.46%
2.3960	66.9 ± 0.5	3403.9 ± 58.9	15.9 ± 9.4	0.04%
2.6444	33.7 ± 0.2	992.5 ± 32.6	13.2 ± 10.1	1.33%
2.6464	34.0 ± 0.3	897.5 ± 30.6	12.1 ± 10.5	1.35%

- Mass distribution and Dalitz plot at 2.0 GeV

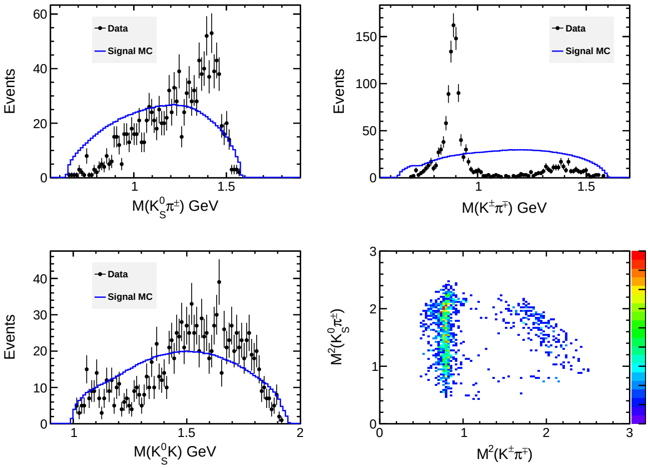


- Mass distribution and Dalitz plot at 2.05 GeV



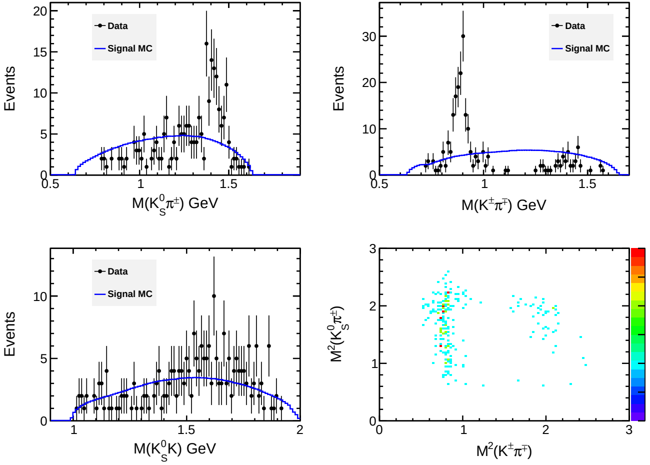
2.1 GeV

- Mass distribution and Dalitz plot at 2.1 GeV

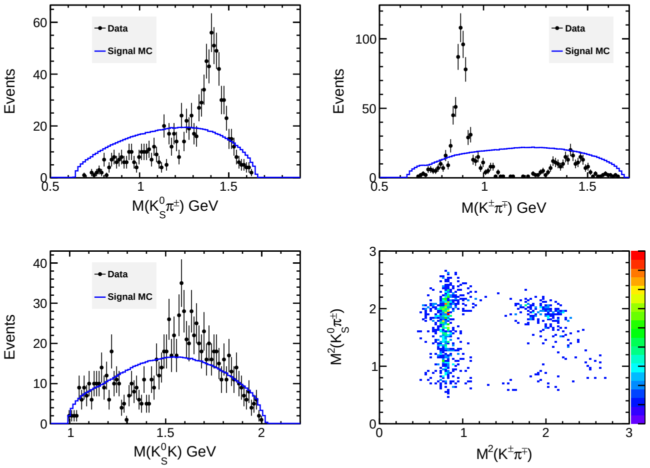


2.15 GeV

- Mass distribution and Dalitz plot at 2.15 GeV

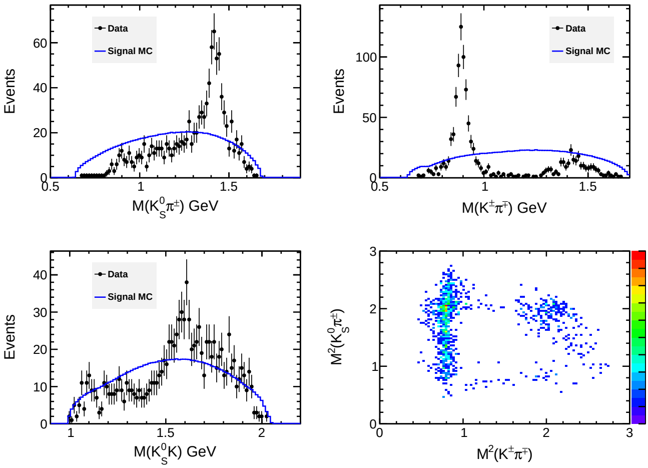


- Mass distribution and Dalitz plot at 2.175 GeV

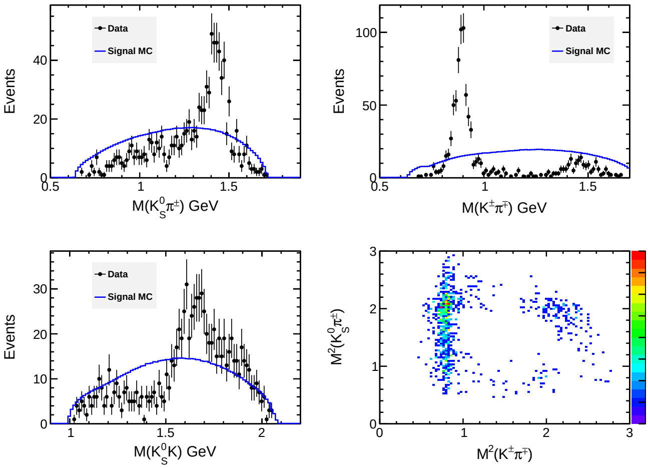


2.2 GeV

- Mass distribution and Dalitz plot at 2.2 GeV

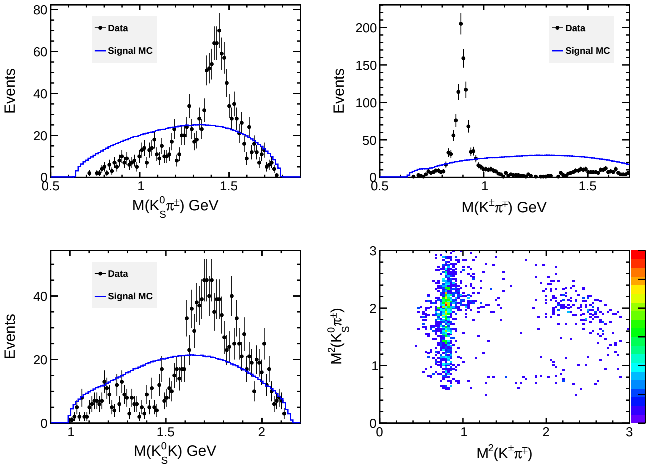


- Mass distribution and Dalitz plot at 2.2324 GeV



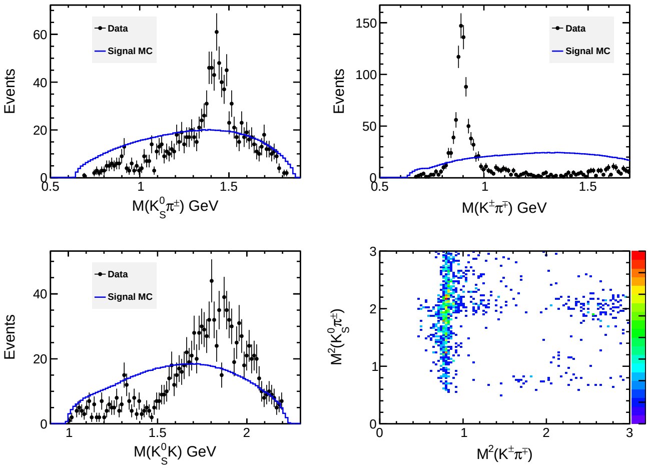
2.3094 GeV

- Mass distribution and Dalitz plot at 2.3094 GeV

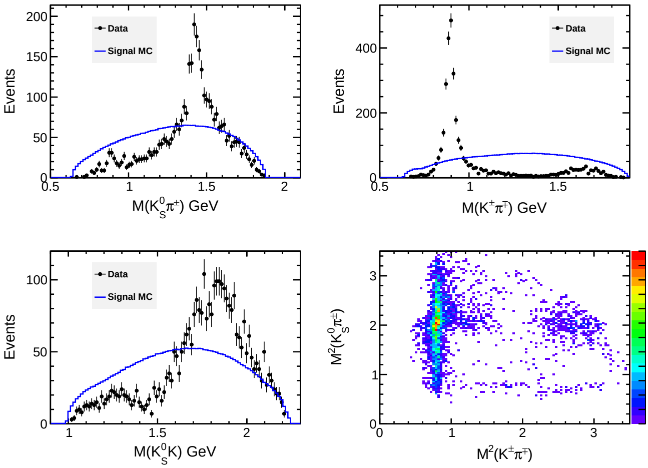


2.3864 GeV

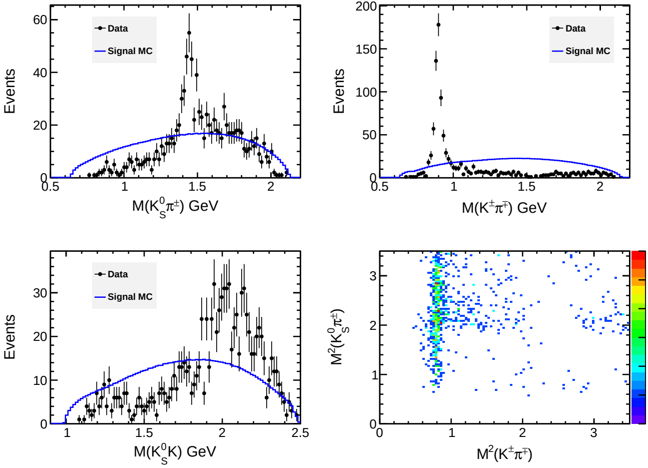
- Mass distribution and Dalitz plot at 2.3864 GeV



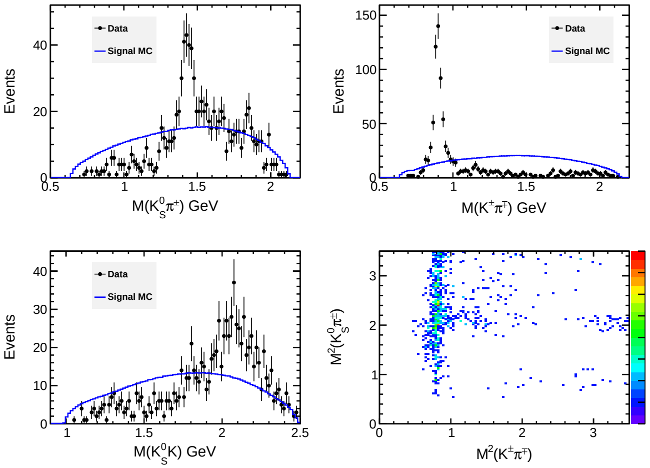
- Mass distribution and Dalitz plot at 2.396 GeV



- Mass distribution and Dalitz plot at 2.6444 GeV



- Mass distribution and Dalitz plot at 2.6464 GeV



Summary and Next To Do

Summary

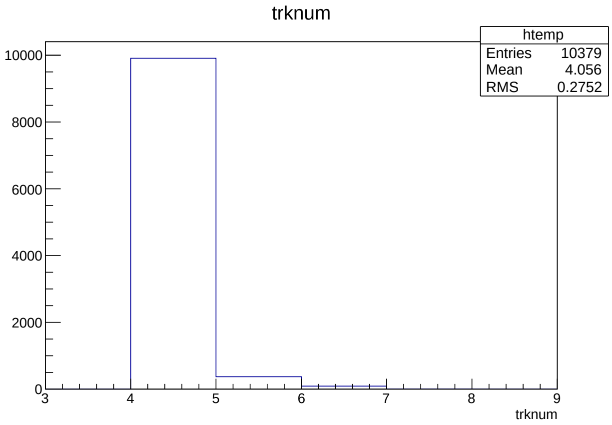
- Event selection has been finished.
- K_S^0 and $K^*(892)$ signal are observed.

Next to do

- Prepare for PWA

Back Up

- Signal MC: $N_{Charged}$ distribution $(N_{Charged} > 3)$



PWA

- Amplitude: covariant tensor formalism
- For the channel $e^+e^- \to K_S^0 K^\pm \pi^\mp$, numbering $K_S^0, K^\pm, \pi^\mp$ as particle 1, 2, 3. Possible partial-wave amplitudes are following:
  - For $e^+e^- \to \rho^\pm \pi^\mp \to (K_S^0 K^\pm)\pi^\mp$, i.e. $e^+e^- \to (12)3$

$$\rho(1450)^\pm\pi^\mp : U^\mu_{\rho^\pm} = \epsilon_{\mu\nu\lambda\sigma} p^\sigma_{(K_S^0 K^\pm \pi^\mp)} \tilde{T}^{(1)\nu}_{\rho^\pm 3} \cdot f^{\rho^\pm}_{12} \cdot \tilde{T}^{(1)\lambda}_{12} \tag{1}$$

$$a_2(1320)^\pm\pi^\mp : U^\mu_{a_2^\pm} = \epsilon_{\mu\nu\lambda\sigma} p^\sigma_{(K_S^0 K^\pm \pi^\mp)} \tilde{T}^{(2)\nu\alpha}_{a_2^\pm 3} \cdot f^{a_2^\pm}_{12} \cdot \tilde{T}^{(2)\lambda}_{12,\alpha} \tag{2}$$

  - For $e^+e^- \to K^{*\pm} K^\mp \to (K_S^0 \pi^\pm)K^\mp$, i.e. $e^+e^- \to (13)2$

$$K^*(892)^\pm K^\mp : U^\mu_{K_1^{*\pm}} = \epsilon_{\mu\nu\lambda\sigma} p^\sigma_{(K_S^0 K^\pm \pi^\mp)} \tilde{T}^{(1)\nu}_{K^{*\pm} 2} \cdot f^{K_1^{*\pm}}_{13} \cdot \tilde{T}^{(1)\lambda}_{13} \tag{3}$$

$$K_2^*(1430)^\pm K^\mp : U^\mu_{K_2^{*\pm}} = \epsilon_{\mu\nu\lambda\sigma} p^\sigma_{(K_S^0 K^\pm \pi^\mp)} \tilde{T}^{(2)\nu\alpha}_{K_2^{*\pm} 2} \cdot f^{K_2^{*\pm}}_{13} \cdot \tilde{T}^{(2)\lambda}_{13,\alpha} \tag{4}$$

PWA

- For $e^+e^- \to K^{*0}K_S^0 \to (K^\pm\pi^\mp)K_S^0$, i.e. $e^+e^- \to (23)1$

$$K^*(892)^0K_S^0 : U^{\mu}_{K_1^{*0}} = \epsilon_{\mu\nu\lambda\sigma}\, p^{\sigma}_{(K_S^0K^\pm\pi^\mp)}\, \tilde{T}^{(1)\nu}_{K_1^{*0}1} \cdot f_{23}^{K_1^{*0}} \cdot \tilde{T}^{(1)\lambda}_{23} \tag{5}$$

$$K_2^*(1430)^0K_S^0 : U^{\mu}_{K_2^{*0}} = \epsilon_{\mu\nu\lambda\sigma}\, p^{\sigma}_{(K_S^0K^\pm\pi^\mp)}\, \tilde{T}^{(2)\nu\alpha}_{K_2^{*0}1} \cdot f_{23}^{K_2^{*0}} \cdot \tilde{T}^{(2)\lambda}_{23,\alpha} \tag{6}$$

- Resonance description
  - Mass-dependent relativistic Breit-Wigner function:

$$BW(s) = \frac{1}{s - M_R^2 + i\sqrt{s}\Gamma_R(s)} \tag{7}$$

$$\Gamma_R(s) = \Gamma_R^0\left(\frac{M_R^2}{s}\right)\left(\frac{p(s)}{p(M_R^2)}\right)^{2l+1} \tag{8}$$

PWA

- First attempt

Resonance	J^P	Mass(GeV/c^2)	Width(GeV)	Significance
$\rho(1450)^{\pm}$	1^-	1.465 ± 0.025	0.400 ± 0.060	5.6σ
$a_2(1320)^{\pm}$	2^+	1.316 ± 0.009	0.107 ± 0.005	26.79σ
$K^*(892)^{\pm}$	1^-	0.891 ± 0.002	0.050 ± 0.001	7.31σ
$K_2^*(1430)^{\pm}$	2^+	1.427 ± 0.001	0.100 ± 0.002	$>50\sigma$
$K^*(892)^0$	1^-	0.896 ± 0.001	0.047 ± 0.001	$>50\sigma$
$K_2^*(1430)^0$	2^+	1.432 ± 0.001	0.109 ± 0.005	22.56σ
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- Mass distribution and angular distribution plot