γKsKpi, γKKpi0

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$\psi' \to \gamma\eta_c', \eta_c' \to KK\pi^0$

Initial Event Selection

Charged Tracks: nGood=2, nCharge=0

- $R_{vz} < 10$cm
- $R_{vxy} < 1$cm
- $cos\theta < 0.93$

Good Photons: nGam>= 3

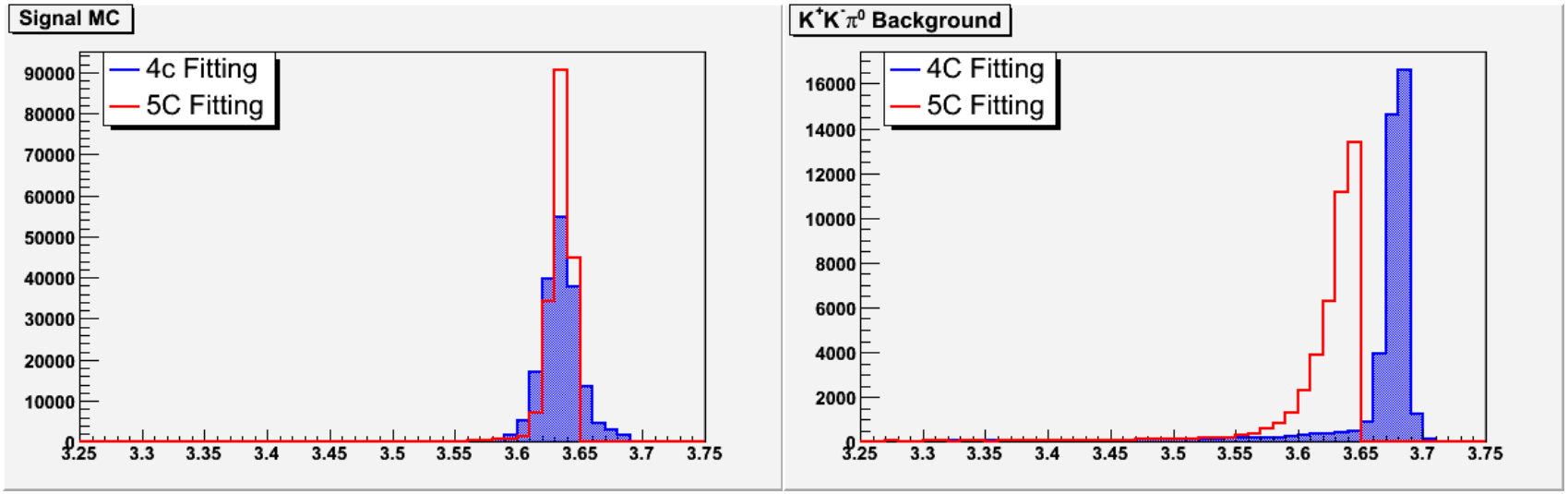
- energy> 40 MeV
- time in [0,14] (*50 ns)
- At 20 degree from the extrapolation of a MDC track.

PID: 1 K+, 1 K-

- TOF, dE/dx
- $p(K) > p(\pi)$,$p(K) > 0.001$

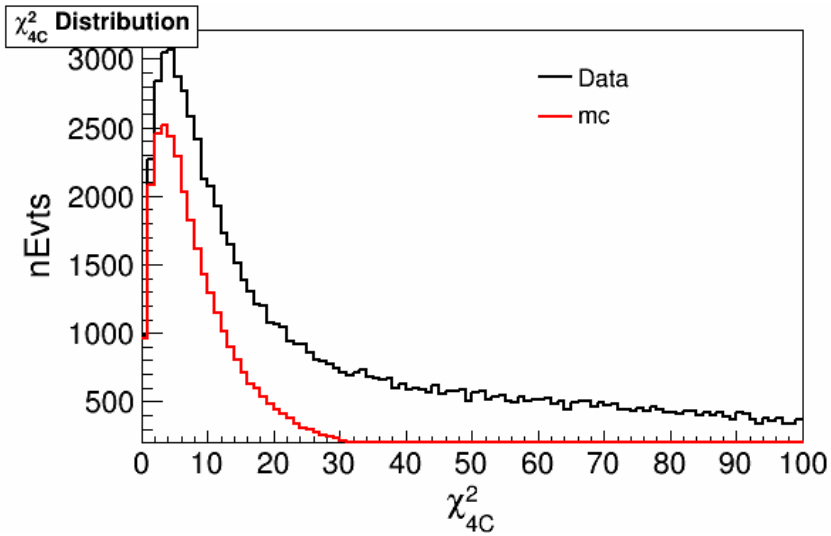
Kinematic Fit

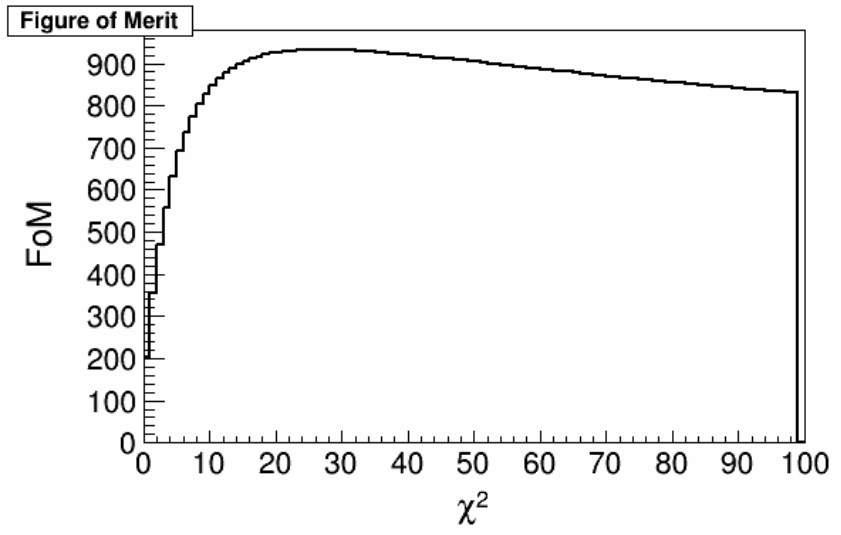
- 5c kinematic fit(p4, mpi0) to decide the choice of γ
- 4c kinematic fit(5C + unfix m(γ_{rad})) for mass representation



Kinematic Fit

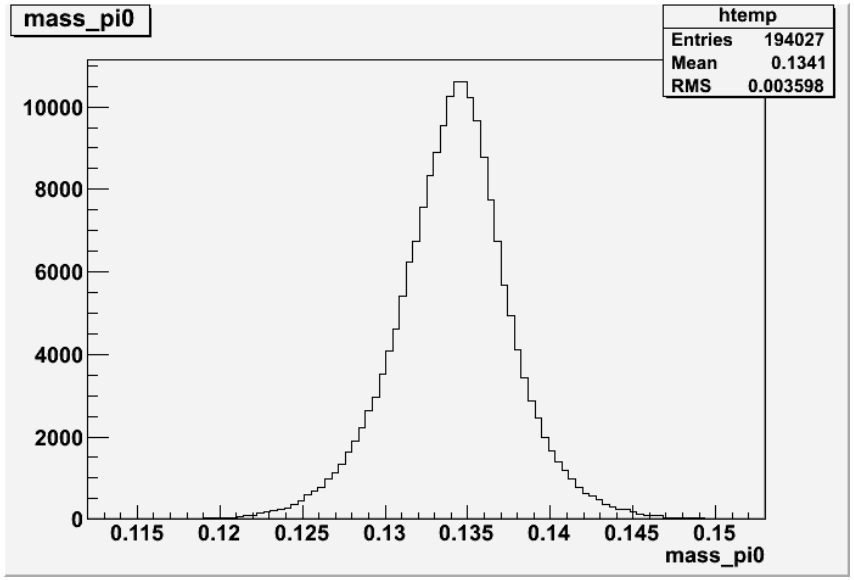
- $\chi^2_{4c} < 30$





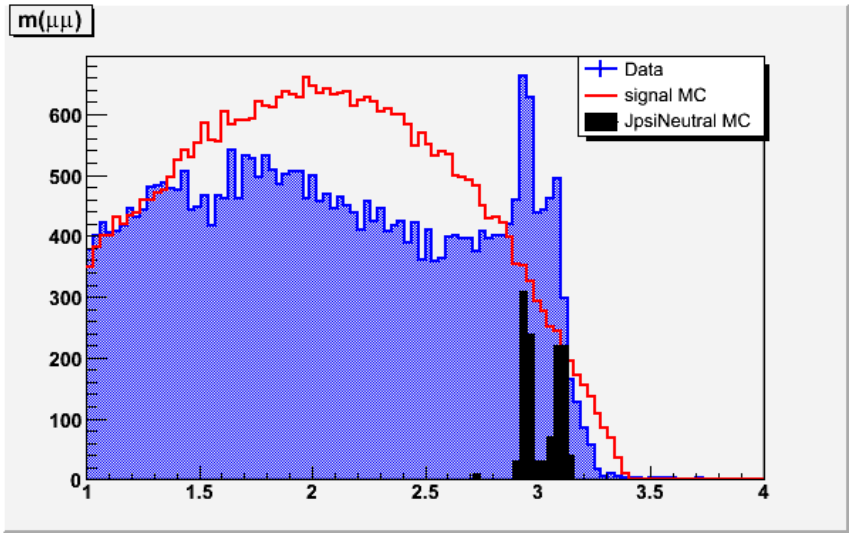
π^0 mass requirement

m(π^0) in range [0.127,0.141].



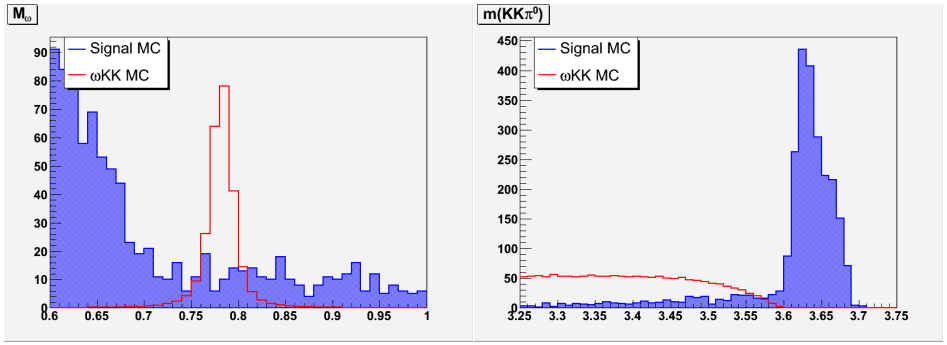
$\psi' \to Neutral + J/\psi$, $J/\psi \to \mu\mu/KK$ background

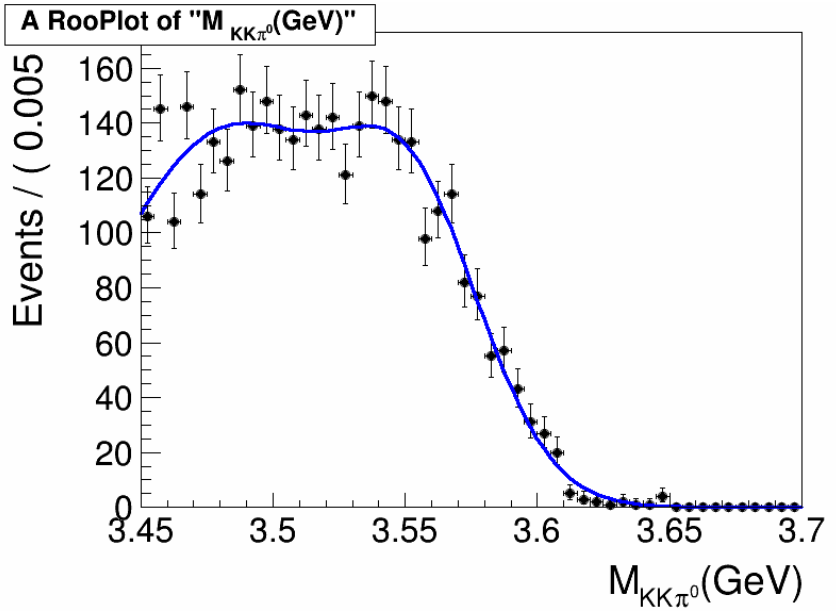
Require $M(\mu\mu) < 2.9$, where $M(\mu\mu)$ is calculated by assuming the two charged tracks as μ.



$\psi' \to \omega KK$ background

Require M(3γ) outside of [0.74, 0.82]. The remaining spectrum is fit to double gaussian.



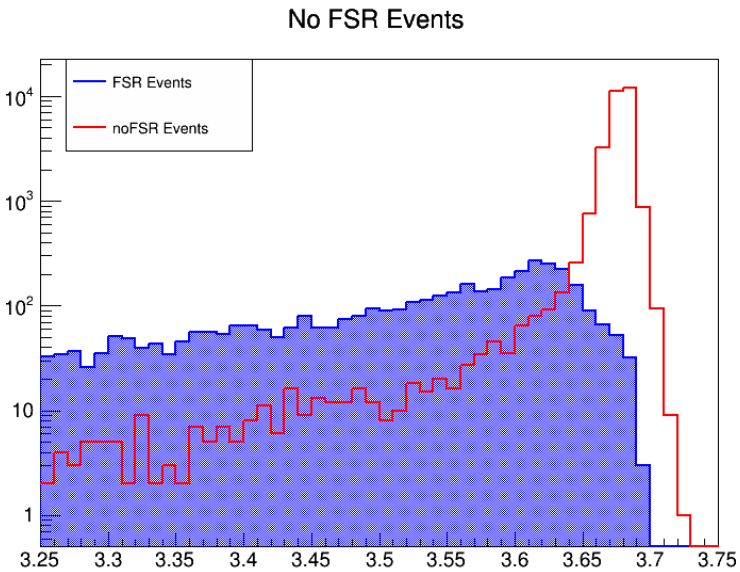


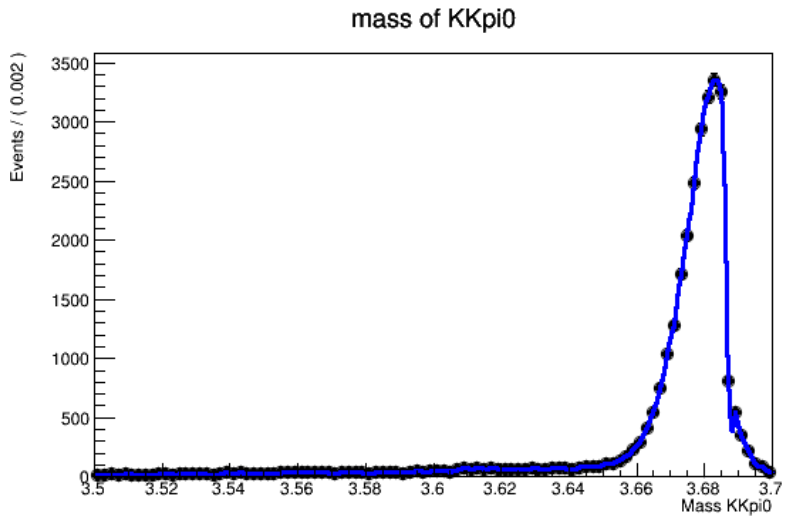
$\pi^0 KK$ background shape

f_{FSR} describe the difference of FSR ration in data/MC. Calculating from existing result:

$$f_{\gamma KK\pi^0} = 2 * f_{\gamma KK\pi\pi} - f_{\pi\pi\pi\pi} = 1.08 \pm 0.15 \quad (1)$$

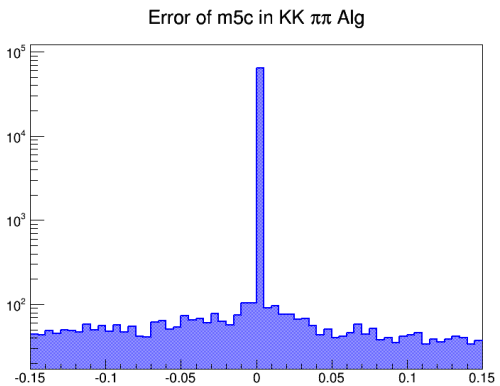
Get the lineshape from the reweighted sum of the FSR and no-FSR events.

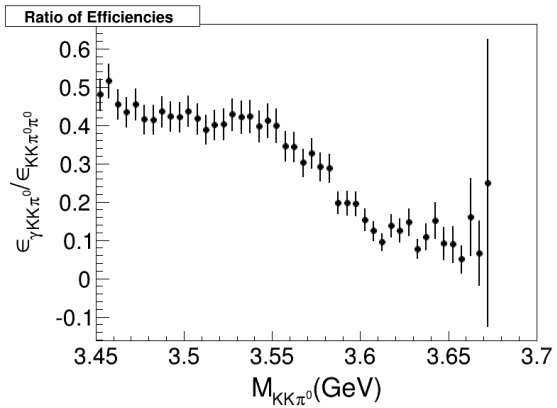


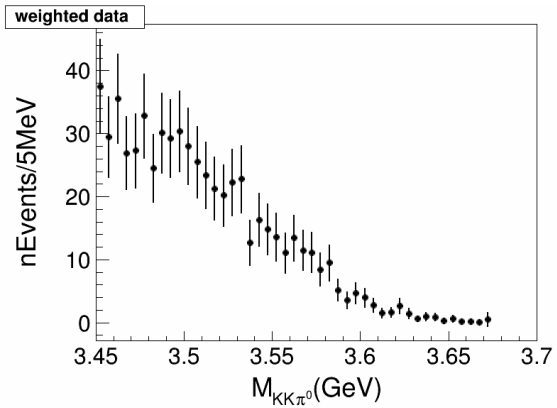


$\pi^0\pi^0KK$ background (fake 5c mass)

Run $KK\pi\pi$ algorithm on data, re-weight the mass spectrum with the ratio of efficiency when $KK\pi^0\pi^0$ MC events try to pass the $\gamma KK\pi^0$ and $KK\pi\pi$ algorithms, to get the $KK\pi^0\pi^0$ contribtution in $\gamma KK\pi$ Alg's result.
The mass in $KK\pi\pi$ algorithm is calculated from a 5C kinematic fit (the best fit when missing 1 photon in $KK\pi^0\pi^0$ candidates) without chisquare requirement.

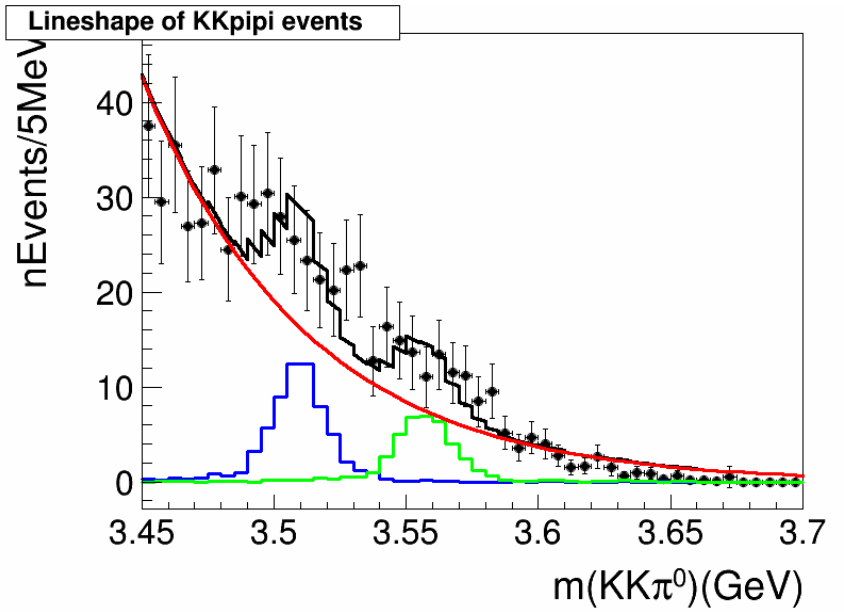






$\pi^0\pi^0KK$ background shape (fake 5c mass)

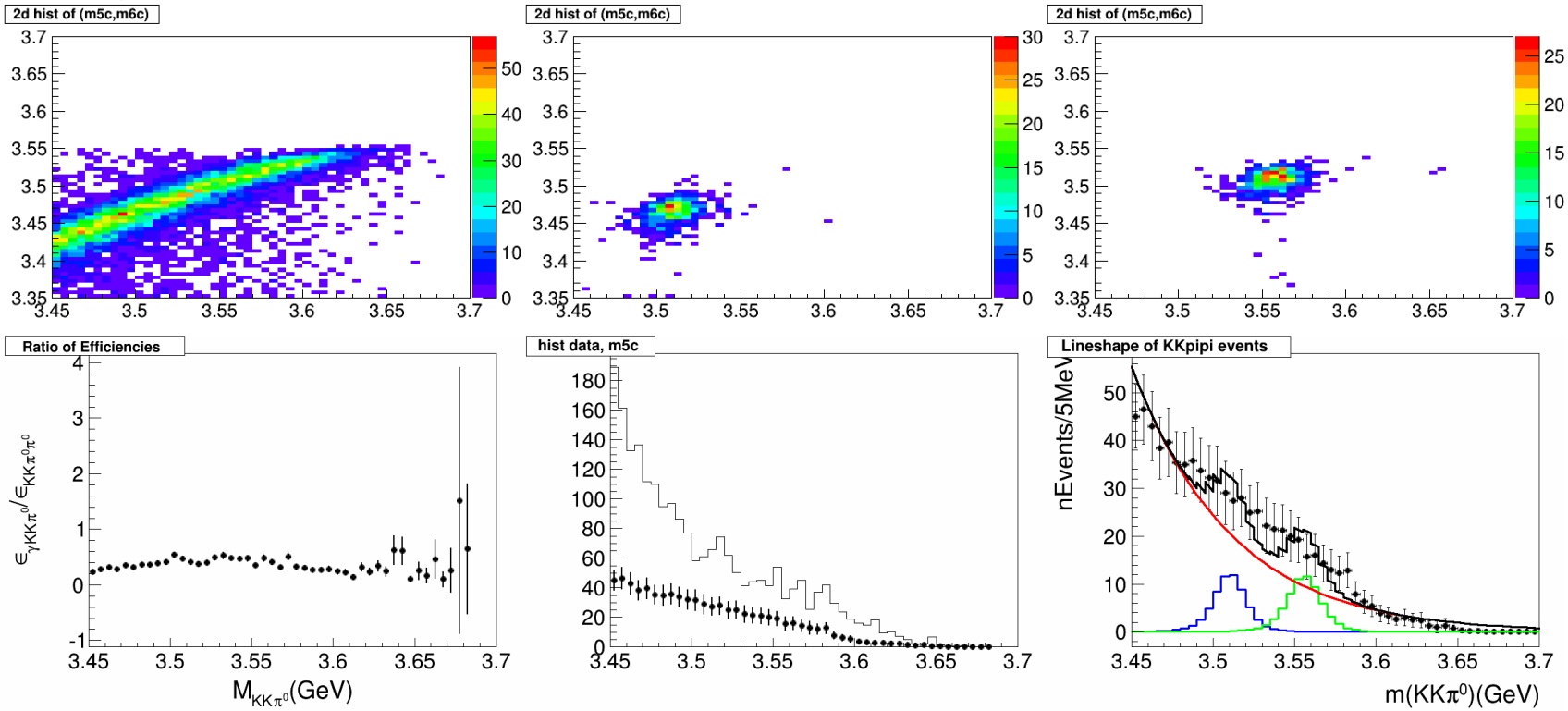
The $KK\pi\pi$ background is described with a Gaussian Function. To get its parameters, the χ_{cj} background are considered by using MC shape.
Fit Result: mean=0.0 $\pm$ 8.8, sigma=0.464 $\pm$ 0.000



$\pi^0\pi^0KK$ background (mass transforming matrix)

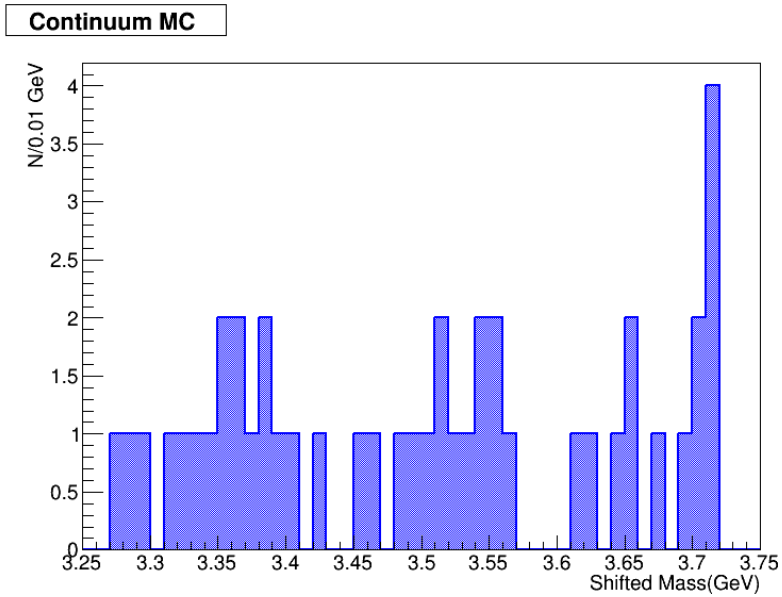
Alternatively, get the matrix of (5c mass, 6c mass) from 10 mil. $\pi^0\pi^0KK$ MC events, and transform the hists accordingly.

Assuming χ_{c1} and χ_{c2} masses distribute in the same way.



Continuum Background

Estimated from $42.6pb^{-1}$ data @ 3650 MeV.

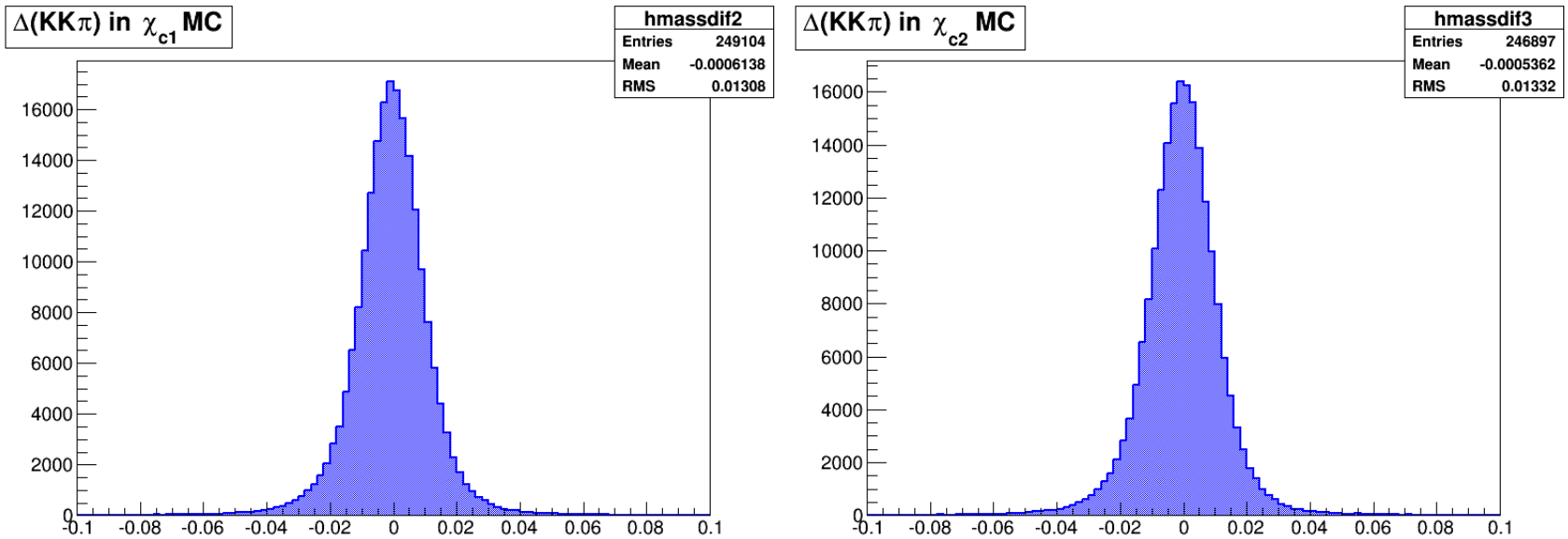


Lineshape Description

- χ_{cj}: MC shape convolved with a gaussian
- $\eta_c(2S)$: $(BW(m) \times E_\gamma^3 \times dampingFunc) \bigotimes Gaussian$
- Damping Function: $\frac{E_0^2}{E_\gamma E_0 + (E_\gamma - E_0)^2}$(KEDR) or $exp(-E_\gamma^2/8\beta^2)$ (CLEO)
- Background Shapes: ωKK as double Gaussian, $KK\pi\pi$ as Gaussian, $KK\pi^0$ as re-weighted MC shape
- Continuum background not considered in fit.

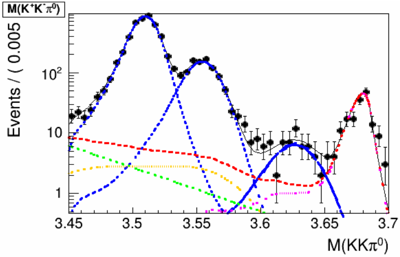
Resolution of Gauss

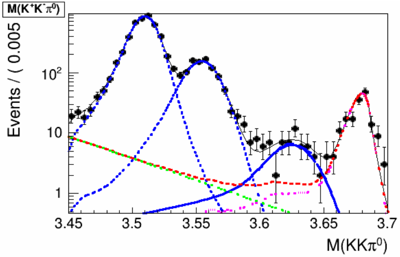
χ_{c1}: width=13.08 MeV, chi_{c2}: width=13.32 MeV;
with linear extrapolation, for η_c width=13.76 MeV

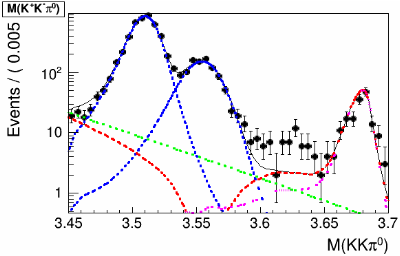


Fit Result

Left: KEDR damping function; Right: CLEO damping function.







Things that needs further checking:

- $\pi^0\pi^0 KK$ lineshape parameters
- Continuum Background
- CLEO damping function

$$\psi' \to \gamma\eta_c', \eta_c' \to K_s K\pi$$

Event Selection

Charged Tracks: nGood=4, nCharge=0

- $R_{vz} < 10$cm
- $R_{vxy} < 1$cm
- $cos\theta < 0.93$

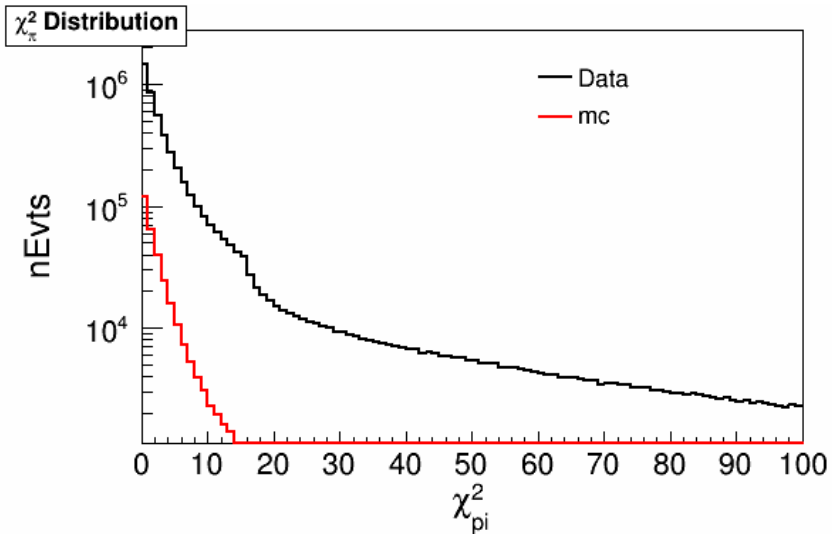
Good Photons: nGam>= 1

- energy> 40 MeV
- time in [0,14] (*50 ns)
- At 20 degree from the extrapolation of a MDC track.

PID:

- TOF, dE/dx
- χ^2_K, χ^2_π of each track saved for later cuts

χ^2 of PID


χ^2_π Distribution
Data
mc
nEvts
10^6
10^5
10^4
0 10 20 30 40 50 60 70 80 90 100
χ^2_{pi}

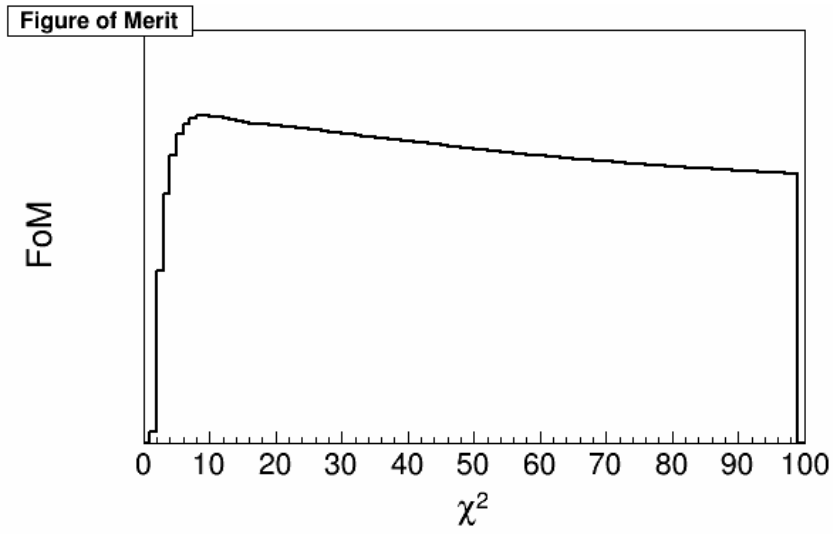
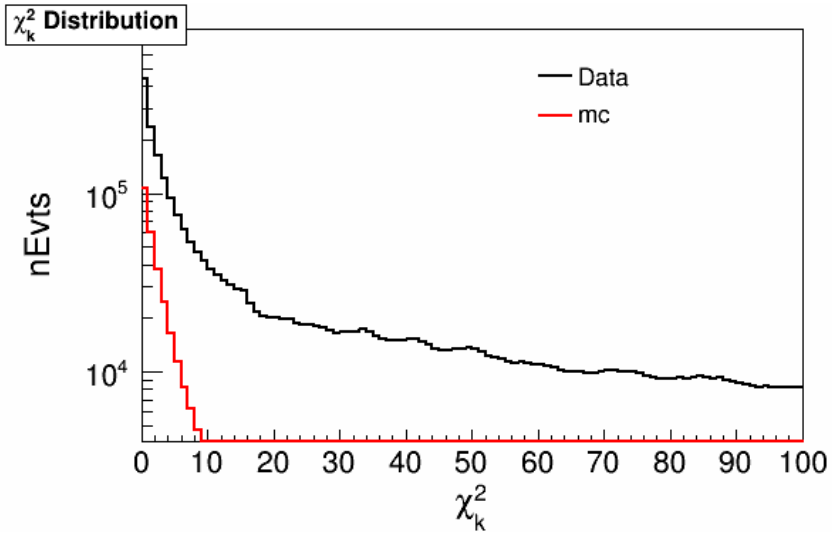


Figure of Merit
FoM
0 10 20 30 40 50 60 70 80 90 100
χ^2


χ^2_k Distribution
Data
mc
nEvts
10^5
10^4
0 10 20 30 40 50 60 70 80 90 100
χ^2_k

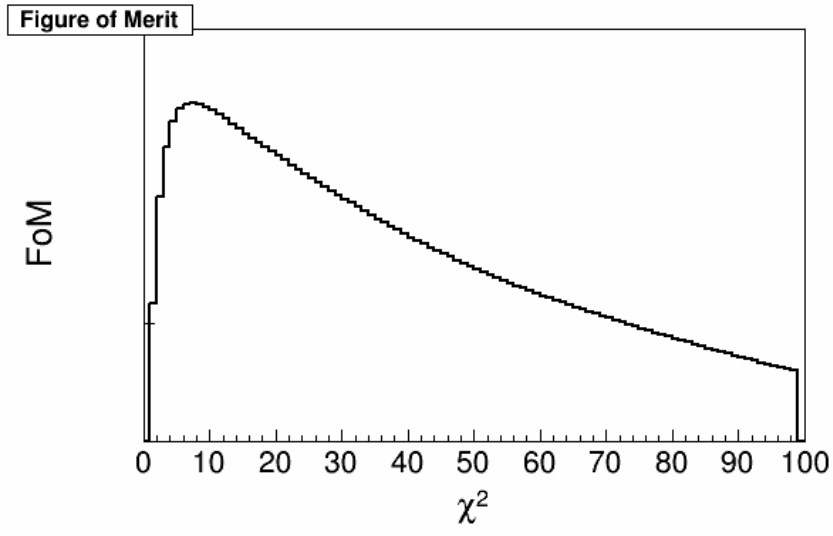


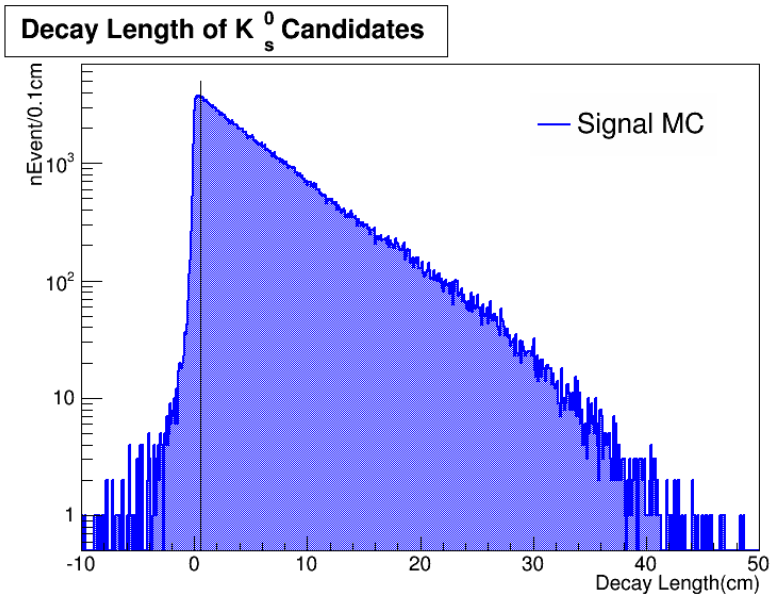
Figure of Merit
FoM
0 10 20 30 40 50 60 70 80 90 100
χ^2

Secondary Vertex Fit

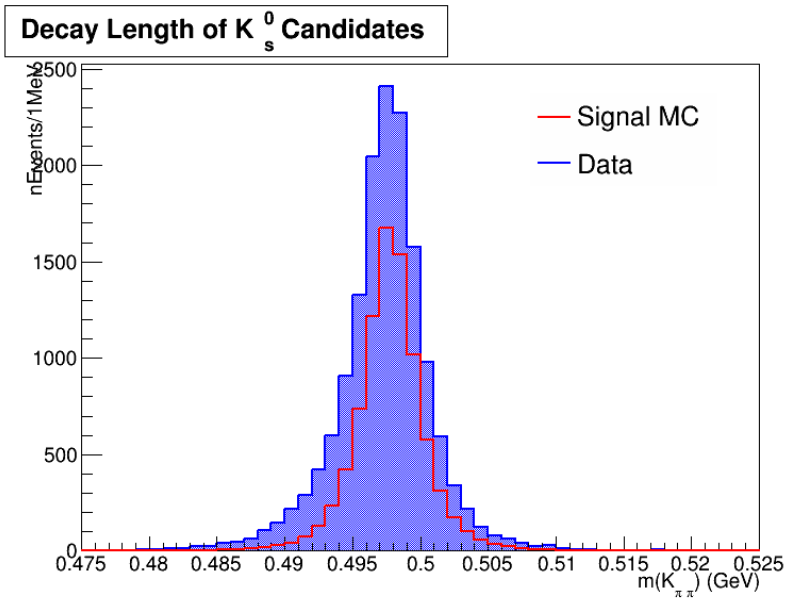
Secondary Vertex Fit for K_s

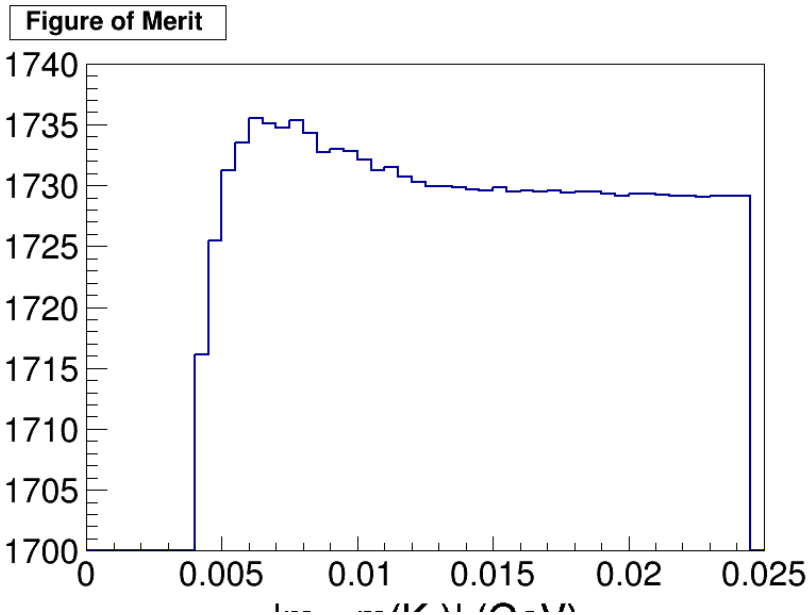
- decay length at least 0.5 cm
- mass within [-7 MeV, +7 MeV] around m(K_s)
- candidate with minimal $(\chi^2_{vtx} + \chi^2_{svtx})$ is chosen

Secondary Vertex Fit - K_s decay length

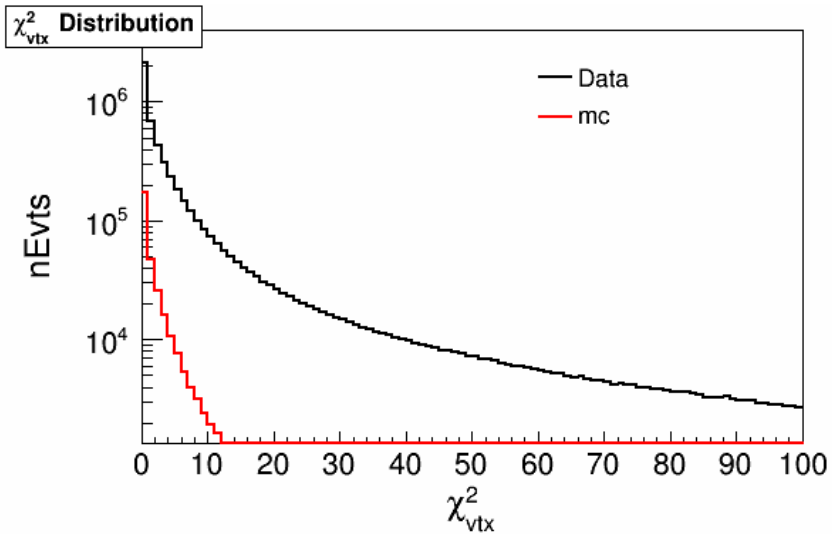


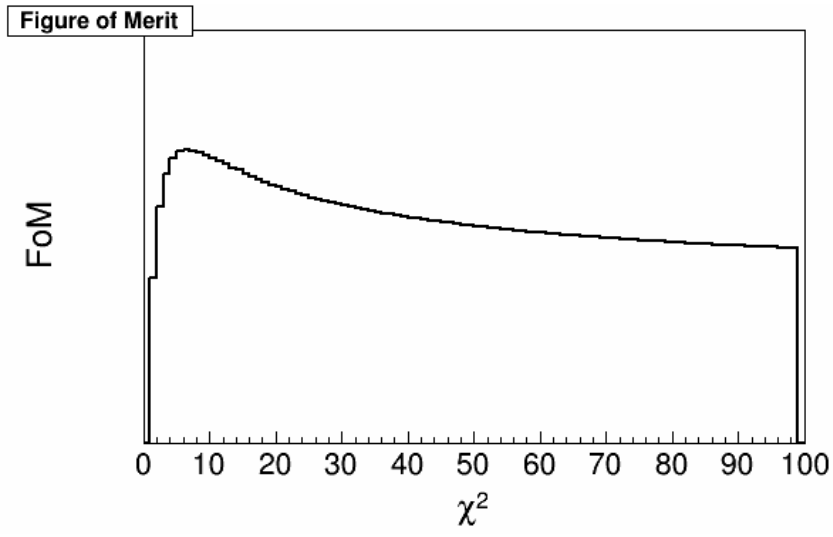
Secondary Vertex Fit - K_s Mass Window

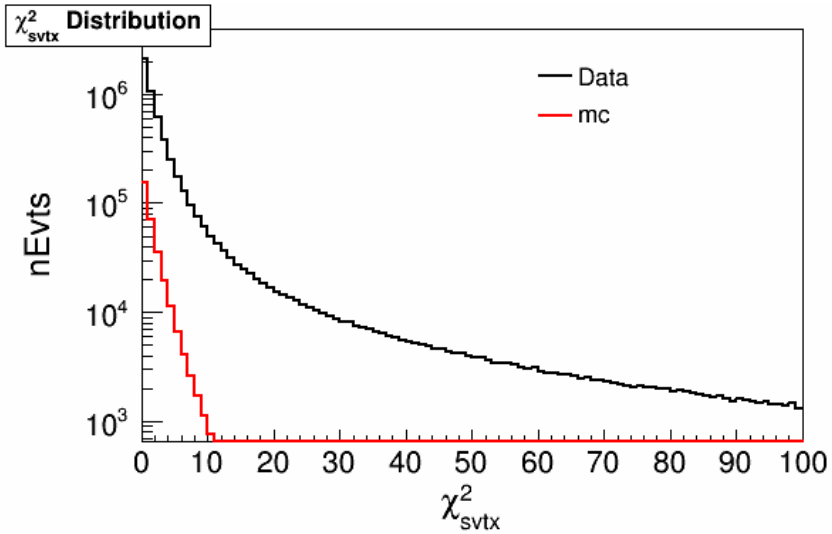


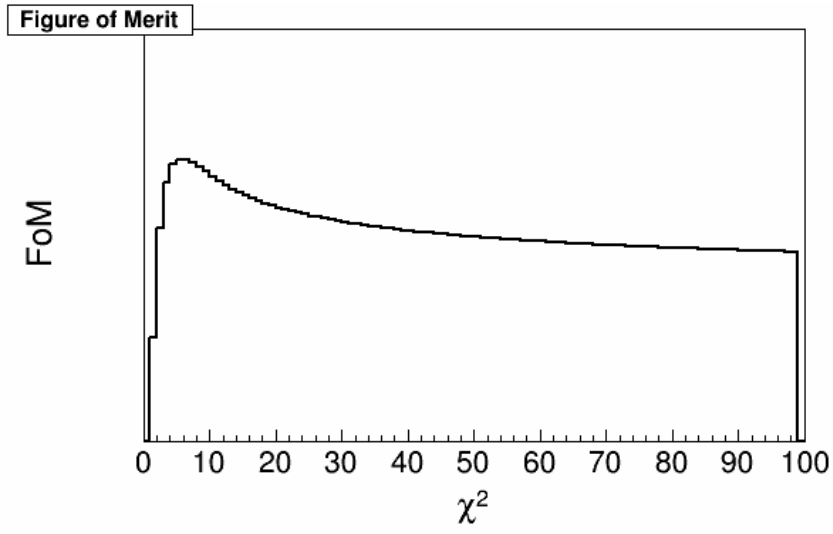


χ^2 of vertex fit and secondary vertex fit



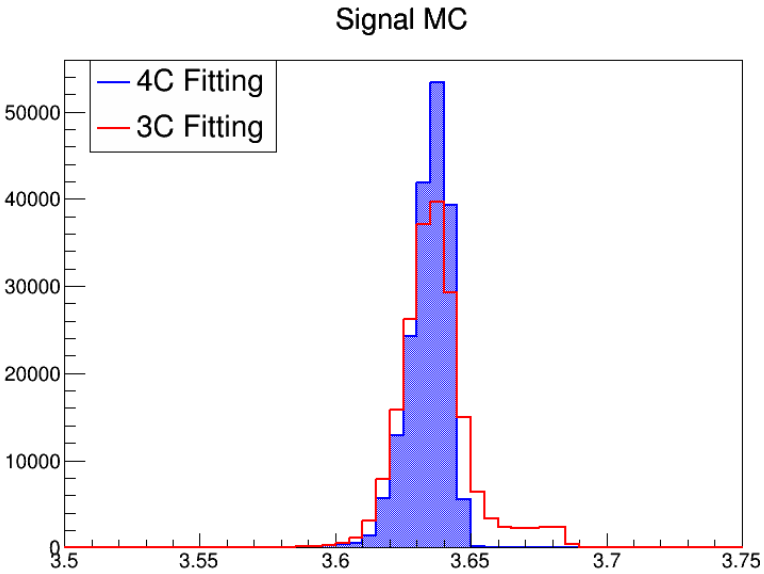


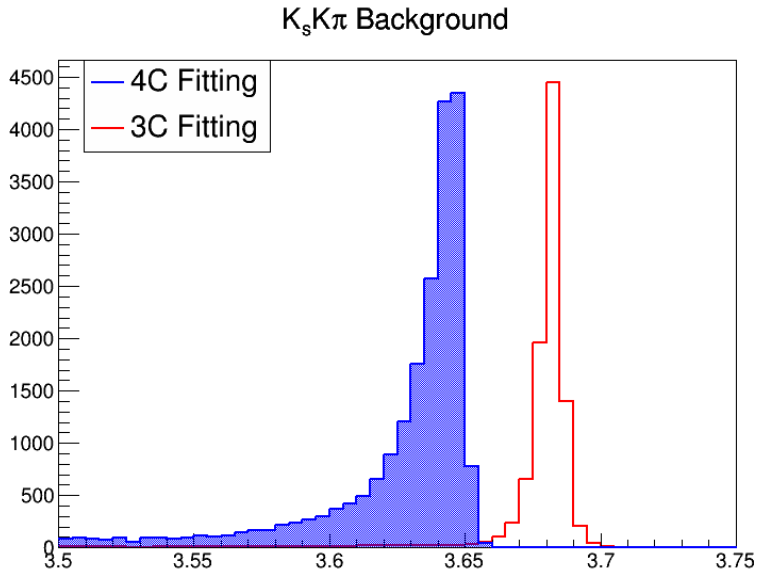




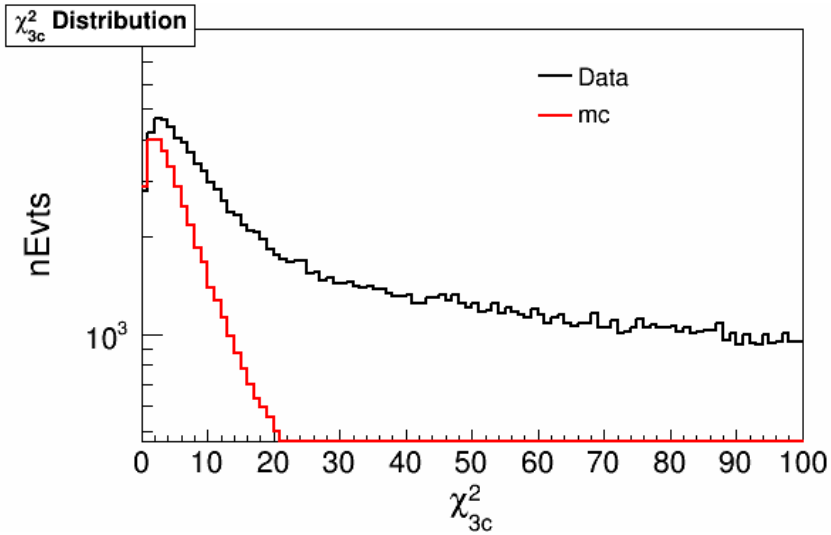
Kinematic Fit

3C: 4 momentum, loosen γ mass.
Iterating over either track being K, and over γ candidates. Combination with minimal $(\chi^2_\pi + \chi^2_K + \chi^2_{kmfit})$ is chosen.





χ^2 of 3C


χ^2_{3c} Distribution
Data
mc
nEvts
10^3
0 10 20 30 40 50 60 70 80 90 100
χ^2_{3c}

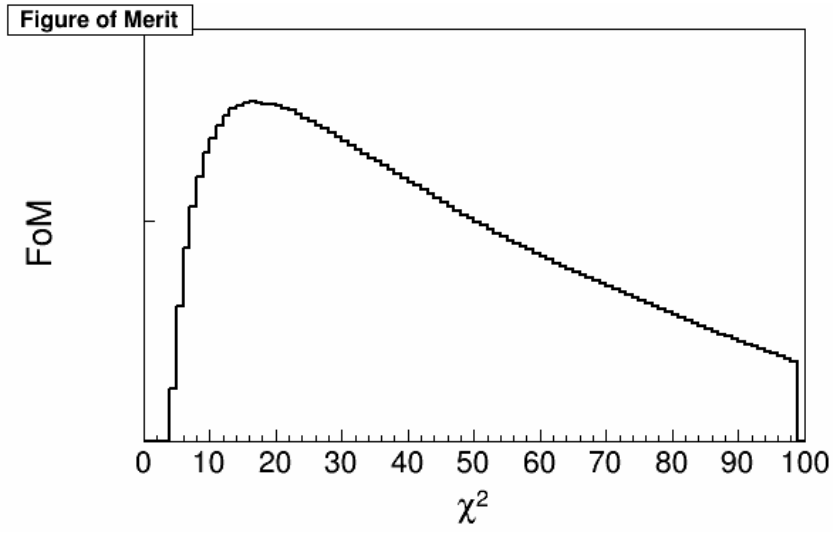
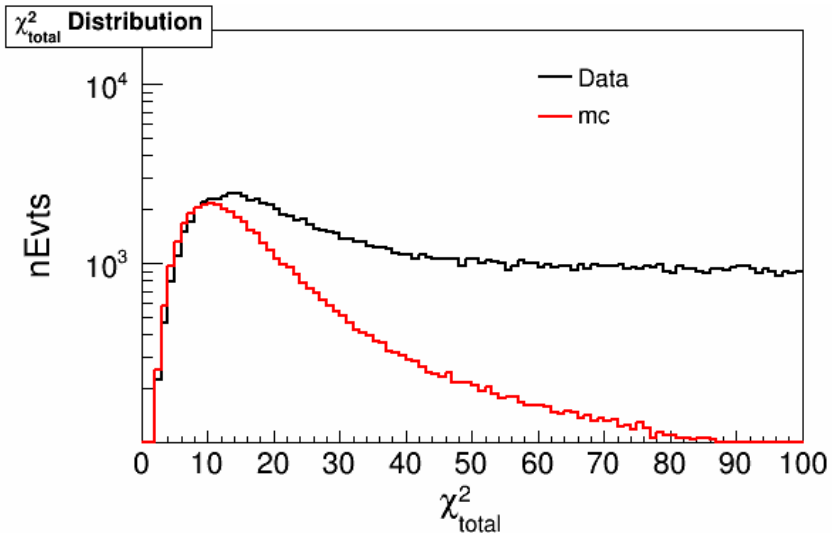
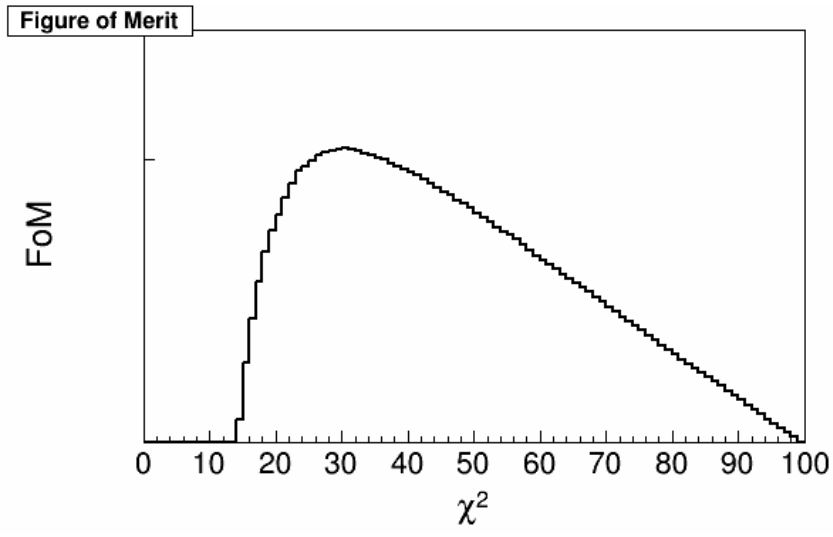


Figure of Merit
FoM
0 10 20 30 40 50 60 70 80 90 100
χ^2

χ^2 total

$(\chi^2_{vtx} + \chi^2_{svtx} + \chi^2_k + \chi^2_\pi + \chi^2_{3c}) < 30$ required





Background Composition

No.	decay chain	final states	iTopology	nEvt	nTot
0	$\psi' \to \gamma\chi_{c1}, \chi_{c1} \to K^-\pi^+\bar{K}^0, K_S \to \pi^+\pi^-$	$\pi^-K^-\pi^+\pi^+\gamma$	3	1938	1938
1	$\psi' \to \gamma\chi_{c1}, \chi_{c1} \to K^+\pi^-K^0, K_S \to \pi^+\pi^-$	$\pi^-\pi^-\pi^+\gamma K^+$	1	1932	3870
2	$\psi' \to J/\psi\pi^+\pi^-, J/\psi \to \mu^+\mu^-$	$\mu^+\pi^-\mu^-\pi^+$	0	1772	5642
3	$\psi' \to J/\psi\pi^+\pi^-, J/\psi \to e^+e^-$	$e^+\pi^-e^-\pi^+$	5	1209	6851
4	$\psi' \to \gamma\chi_{c2}, \chi_{c2} \to \bar{K}^0K^+\pi^-, K_S \to \pi^+\pi^-$	$\pi^-\pi^-\pi^+\gamma K^+$	17	534	7385
5	$\psi' \to \gamma\chi_{c2}, \chi_{c2} \to K^0K^-\pi^+, K_S \to \pi^+\pi^-$	$\pi^-K^-\pi^+\pi^+\gamma$	11	482	7867
6	$\psi' \to \gamma\chi_{c0}, \chi_{c0} \to K_SK_S, K_S \to \pi^+\pi^-, K_S \to \pi^+\pi^-$	$\pi^-\pi^-\pi^+\pi^+\gamma$	9	382	8249
7	$\psi' \to \gamma\chi_{c1}, \chi_{c1} \to K^{*+}K^-, K^{*+} \to K^0\pi^+, K_S \to \pi^+\pi^-$	$\pi^-K^-\pi^+\pi^+\gamma$	10	279	8528
8	$\psi' \to \gamma\chi_{c1}, \chi_{c1} \to K^{*-}K^+, K^{*-} \to \bar{K}^0\pi^-, K_S \to \pi^+\pi^-$	$\pi^-\pi^-\pi^+\gamma K^+$	14	257	8785
9	$\psi' \to \gamma\chi_{c1}, \chi_{c1} \to K^*\bar{K}^0, K^* \to K^+\pi^-, K_S \to \pi^+\pi^-$	$\pi^-\pi^-\pi^+\gamma K^+$	12	256	9041
10	$\psi' \to \gamma\chi_{c1}, \chi_{c1} \to \bar{K}^*K^0, \bar{K}^* \to K^-\pi^+, K_S \to \pi^+\pi^-$	$\pi^-K^-\pi^+\pi^+\gamma$	2	209	9250
11	$\psi' \to \gamma K_SK^+\pi^-, K_S \to \pi^+\pi^-$	$\pi^-\pi^-\pi^+\gamma K^+$	6	153	9403
12	$\psi' \to \gamma\chi_{c2}, \chi_{c2} \to K_SK_S, K_S \to \pi^+\pi^-, K_S \to \pi^+\pi^-$	$\pi^-\pi^-\pi^+\pi^+\gamma$	8	136	9539
13	$\psi' \to K_1^+K^-, K_1^+ \to \rho^+K^0, \rho^+ \to \pi^+\pi^0, K_S \to \pi^+\pi^-$	$\pi^-K^-\pi^0\pi^+\pi^+$	19	129	9668
14	$\psi' \to K_1^-K^+, K_1^- \to \rho^-\bar{K}^0, \rho^- \to \pi^-\pi^0, K_S \to \pi^+\pi^-$	$\pi^-\pi^-\pi^0\pi^+K^+$	15	128	9796
15	$\psi' \to \gamma K_SK^-\pi^+, K_S \to \pi^+\pi^-$	$\pi^-K^-\pi^+\pi^+\gamma$	35	117	9913
16	$\psi' \to \bar{K}^*K^0, \bar{K}^* \to K^-\pi^+, K_S \to \pi^+\pi^-$	$\pi^-K^-\pi^+\pi^+$	28	105	10018
17	$\psi' \to K^*\bar{K}^0, K^* \to K^+\pi^-, K_S \to \pi^+\pi^-$	$\pi^-\pi^-\pi^+K^+$	25	98	10116
18	$\psi' \to \gamma\chi_{c1}, \chi_{c1} \to a_0^-\pi^+, a_0^- \to K^0K^-, K_S \to \pi^+\pi^-$	$\pi^-K^-\pi^+\pi^+\gamma$	38	77	10193
19	$\psi' \to K^+\bar{K}^*\pi^-, \bar{K}^* \to \bar{K}^0\pi^0, K_S \to \pi^+\pi^-$	$\pi^-\pi^-\pi^0\pi^+K^+$	20	54	10247
20	$\psi' \to \gamma\chi_{c1}, \chi_{c1} \to a_0^+\pi^-, a_0^+ \to \bar{K}^0K^+, K_S \to \pi^+\pi^-$	$\pi^-\pi^-\pi^+\gamma K^+$	23	52	10299
21	$\psi' \to K^-K^*\pi^+, K^* \to K^0\pi^0, K_S \to \pi^+\pi^-$	$\pi^-K^-\pi^0\pi^+\pi^+$	61	49	10348
22	$\psi' \to K_1^+K^-, K_1^+ \to K_0^{*+}\pi^0, K_0^{*+} \to K^0\pi^+, K_S \to \pi^+\pi^-$	$\pi^-K^-\pi^0\pi^+\pi^+$	7	42	10390
23	$\psi' \to K_1^-K^+, K_1^- \to K_0^{*-}\pi^0, K_0^{*-} \to \bar{K}^0\pi^-, K_S \to \pi^+\pi^-$	$\pi^-\pi^-\pi^0\pi^+K^+$	53	39	10429
24	$\psi' \to \gamma\eta_c(2S), \eta_c(2S) \to K^-K^0\pi^+, K_S \to \pi^+\pi^-$	$\pi^-K^-\pi^+\pi^+\gamma$	66	30	10459
25	$\psi' \to \gamma\eta_c(2S), \eta_c(2S) \to K^+\bar{K}^0\pi^-, K_S \to \pi^+\pi^-$	$\pi^-\pi^-\pi^+\gamma K^+$	108	28	10487
26	$\psi' \to K_1^-K^+, K_1^- \to \bar{K}_0^{*0}\pi^-, \bar{K}_0^{*0} \to \bar{K}^0\pi^0, K_S \to \pi^+\pi^-$	$\pi^-\pi^-\pi^0\pi^+K^+$	13	23	10510
27	$\psi' \to K_1^+K^-, K_1^+ \to K^{*+}\pi^0, K^{*+} \to K^0\pi^+, K_S \to \pi^+\pi^-$	$\pi^-K^-\pi^0\pi^+\pi^+$	65	21	10531
28	$\psi' \to \gamma\chi_{c2}, \chi_{c2} \to K^{*+}K^{*-}, K^{*+} \to K^0\pi^+, K^{*-} \to K^-\pi^0, K_S \to \pi^+\pi^-$	$\pi^-K^-\pi^0\pi^+\pi^+\gamma$	52	21	10552
29	$\psi' \to K_1^+K^-, K_1^+ \to K^*\pi^+, K^* \to K^0\pi^0, K_S \to \pi^+\pi^-$	$\pi^-K^-\pi^0\pi^+\pi^+$	64	21	10573

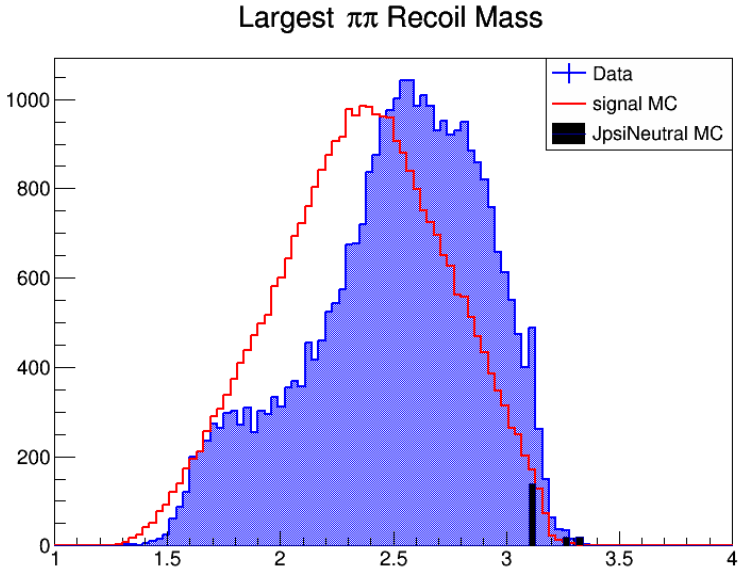
Table 1:

$\gamma K_s K_s$ Background

Require that the two tracks outside the best K_s candidate can't be a K_s candidate.
It's regarded as a K_s candidate if the other two tracks can pass a vertex fit and the invariant mass is in the range of [-10 MeV,+10 MeV] around $m(K_s)$.
The efficiency for $\gamma K_s K_s$*component* without and with such a cut is 1.53% and 0.86%, while it's 18.1% and 18.0% for signal.

J/ψ + Neutral Background

Require the largest recoil mass of $m(\pi\pi)$ of all π pairs to be smaller than 3.05 GeV.



$K_sK\pi$ Background

Study the process of $\psi' \to \gamma\chi_{c1}$, $\chi_{c1} \to K_sK\pi(\gamma_{FSR})$. To get the R_{data}/R_{mc}, where $R = \frac{N_{FSR}}{N_{noFSR}}$.

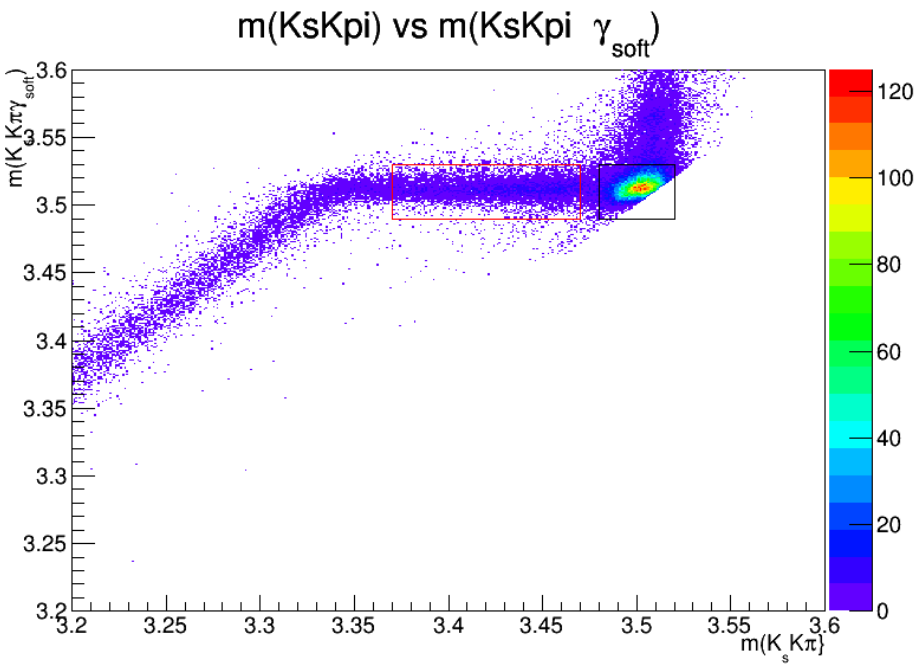
$\gamma\gamma K_sK\pi$ Algorithm

- ngood=4, ncharge=0, nGam>=2
- PID (dE/dx, TOF)(p, k, π) to get chisquare
- secondary vertex fit: m(K_s) in [-15 MeV,+15 MeV]; the other two tracks shouldn't make K_s
- kinematic fit: (4C for combination; 3c for mass, γ_{soft} with flexible mass)

$K_sK\pi$ Background - estimate R_{data}/R_{mc}

$\chi^2_{4c} < 50$, $\chi^2_{vtx} < 30$, $\chi^2_{svtx} < 30$, $len > 0.5$, veto $m(\gamma\gamma)$ in [0.1,0.155]

noFSR Events and FSR Events in boxes. Background events in data identified by truth info in Inclusive MC.



	FSR	noFSR
12mc	147	296
12mc bkg	66	12
09mc	43	68
09mc bkg	18	3
12data	168	206
09data	53	54
χ_{c1} MC(09)	9697	29127

$$R_{mc,09} = 25/65,\ R_{mc,12} = 81/284$$

$$R_{data,09} = 35/51, R_{data,12} = 102/194$$

$$R_{sig} = 9697/29127$$

$K_sK\pi$ Background - estimate R_{data}/R_{mc}

alternative cuts

$\chi^2_{3c} + \chi^2_{vtx} + \chi^2_{svtx} + \chi^2_{\pi} + \chi^2_{k} < 50, len > 0.5$, veto $m(\gamma\gamma)$ in [0.1,0.155]

	FSR	noFSR
12mc	150	1615
12mc bkg	74	43
09mc	47	446
09mc bkg	23	14
12data	175	1205
09data	57	347
χ_{c1} MC(09)	9932	199018

$R_{mc,09} = 24/432$, $R_{mc,12} = 76/1575$

$R_{data,09} = 34/333 = 0.102, R_{data,12} = 101/1162 = 0.0869$

$R_{sig} = 9932/199018 = 0.0499$

$\chi^2_{4c} + \chi^2_{vtx} + \chi^2_{svtx} + \chi^2_{\pi} + \chi^2_{k} < 50, len > 0.5$, veto $m(\gamma\gamma)$ in [0.1,0.155]

	FSR	noFSR
12mc	99	184
12mc bkg	38	4
09mc	33	40
09mc bkg	12	2
12data	124	116
09data	42	26
χ_{c1} MC(09)	8793	16848

$R_{mc,09} = 21/38$, $R_{mc,12} = 61/180$

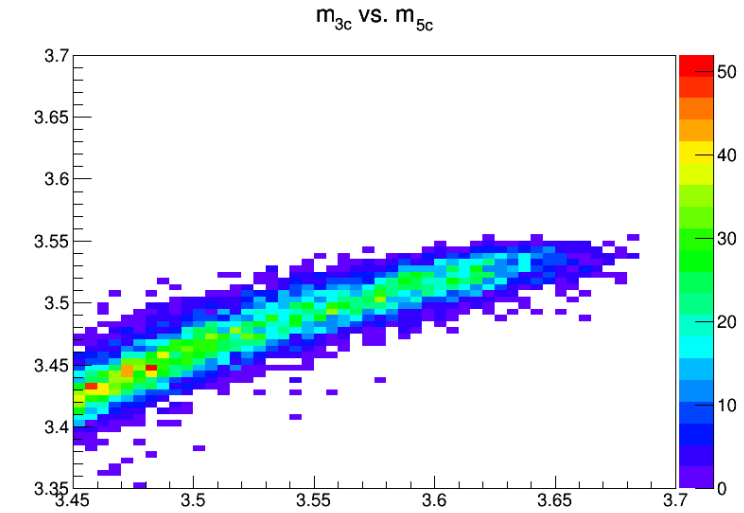
$R_{data,09} = 30/24 = 1.25, R_{data,12} = 86/112 = 0.768$

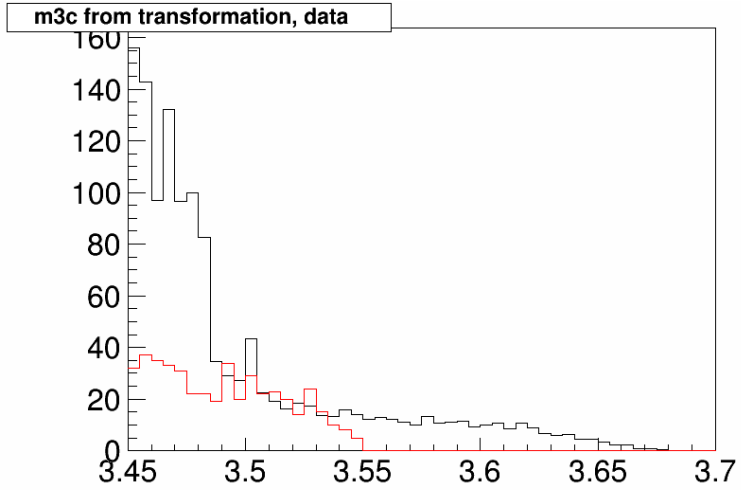
$R_{sig} = 8793/16848 = 0.522$

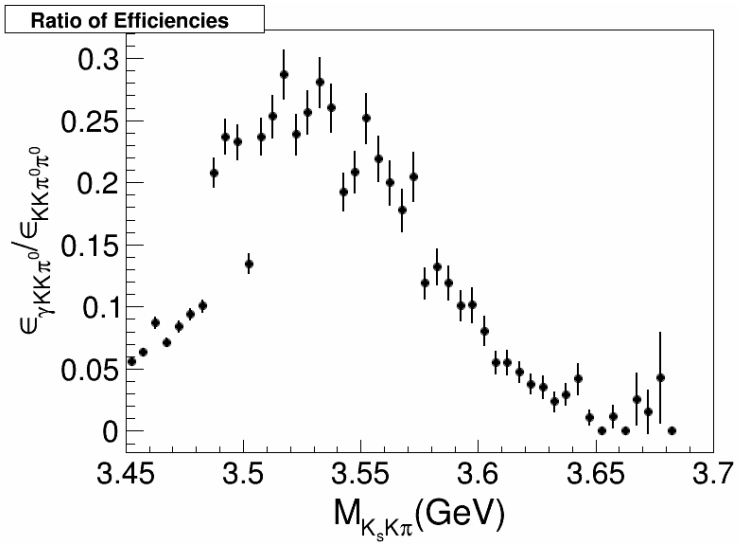
The ratio is decided to be stable; uncertainty around 40%.
n(FSR)/n(noFSR)=7221/82298; taking $R_{data}/R_{mc} = 1.5$.

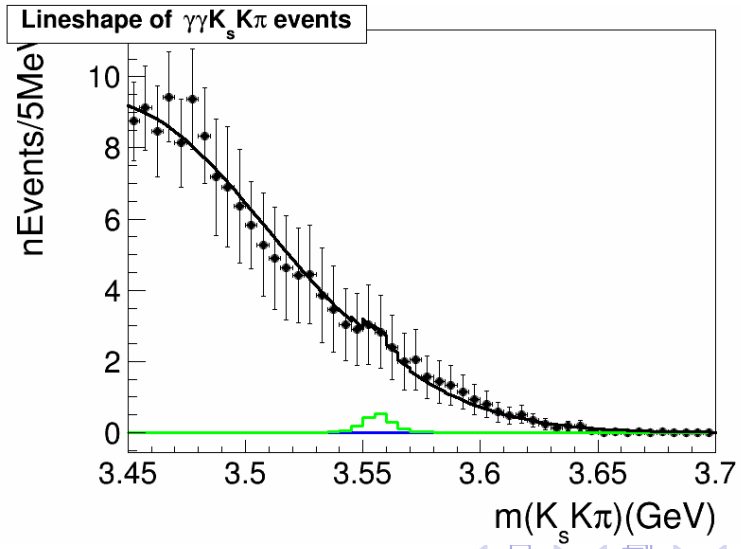
$\pi^0 K_s K\pi$ Background

Gaussian. mean=3.44 ± 0.03, sigma=0.071 ± 0.013









Fit Result

Around 160 events in 2012 data.