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IOcheck of N_{obs} in work $\eta_c \rightarrow \omega\phi$

2022.11.18

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Outline

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- Updated further selection criteria
- Fit result of data
- IOcheck result

Further selecton criteria

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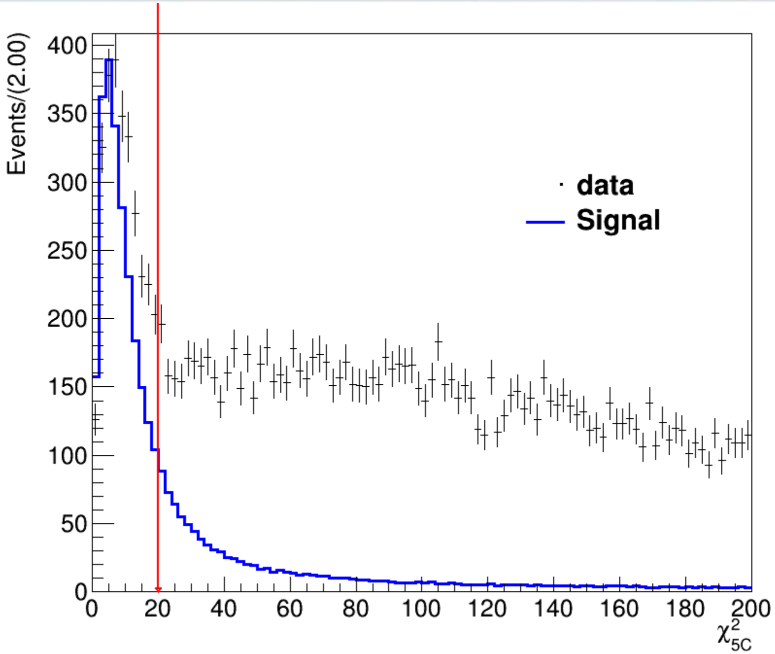
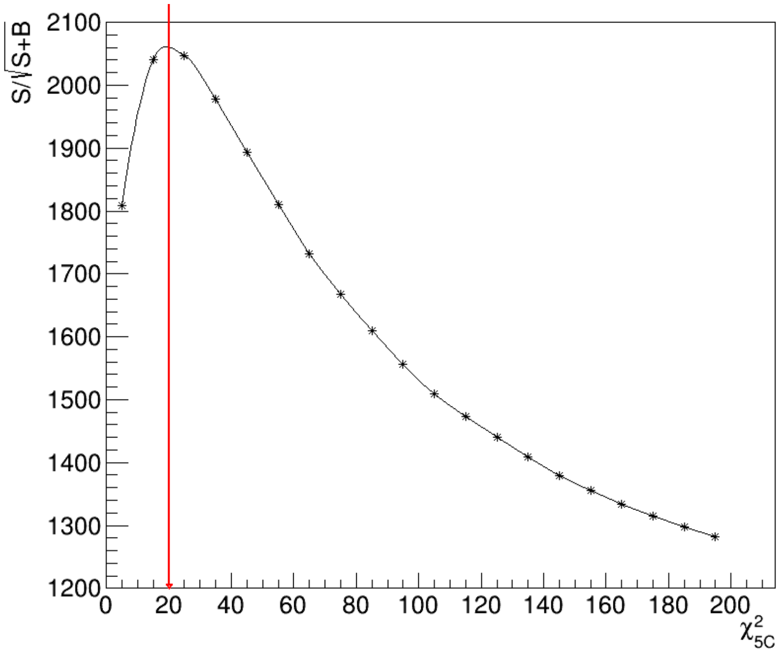
- $2.800 \le M_{\pi^+\pi^-\pi^0 K^+K^-} \le 3.100 GeV/c^2$
- $0.742 \le M_{\pi^+\pi^-\pi^0} \le 0.822\ GeV/c^2$ (ω mass window)
- $1.005 \le M_{K^+K^-} \le 1.035\ GeV/c^2$ (ϕ mass window)
- $\chi^2_{5C} \le 20$
- $|\cos(\theta_{decay})| \le 0.95$ (decay angle of π^0)
- $\left|M_{\gamma\omega} - M_{\eta'}^{PDG}\right| > 0.01 GeV/c^2$ (veto $J/\psi \to \phi\eta'$)

χ^2_{5C} cut

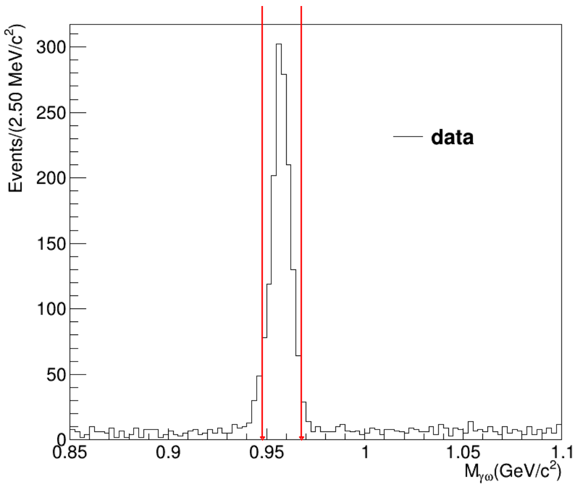


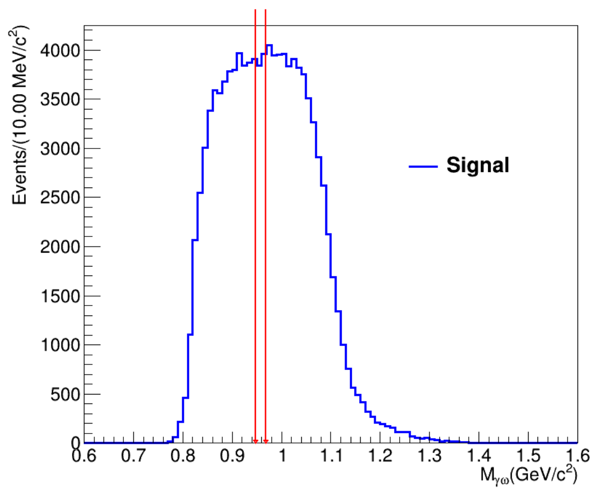
$\chi^2_{5C} \leq 20$



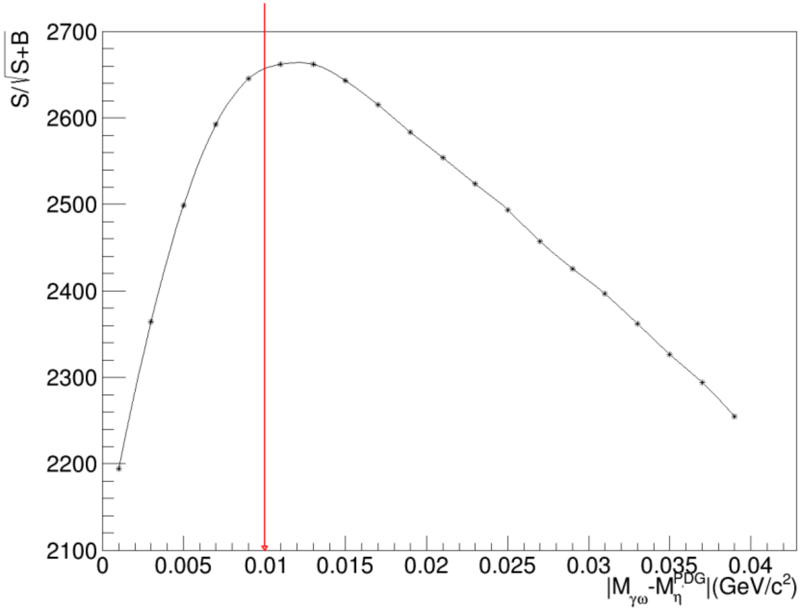
FOM

veto η' at $\gamma\omega$ mass spectrum





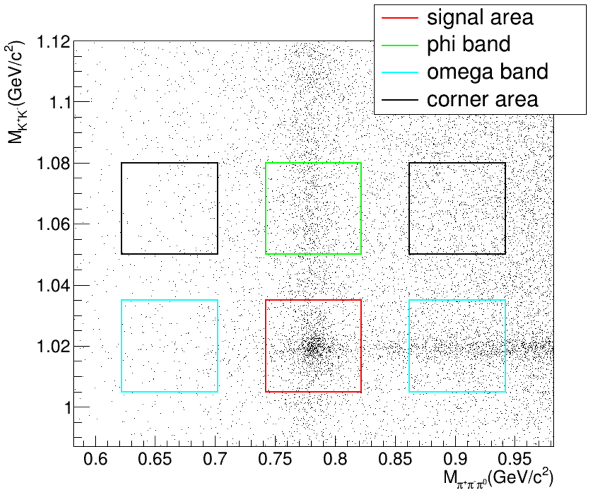
$$\left|M_{\gamma\omega} - M_{\eta'}^{PDG}\right| > 0.01GeV/c^2$$



FOM

2D-sideband method to estimate background

- $\omega - \phi$ signal region (red box)
  - ✓ $|M_{\pi^+\pi^-\pi^0} - M_\omega| \leq 40\ \mathrm{MeV}/c^2$ and $|M_{K^+K^-} - M_\phi| \leq 15\ \mathrm{MeV}/c^2$
- ω sideband region (cyan box)
  - ✓ $|M_{\pi^+\pi^-\pi^0} - M_\omega \pm 120| \leq 40\ \mathrm{MeV}/c^2$ and $|M_{K^+K^-} - M_\phi| \leq 15\ \mathrm{MeV}/c^2$
- ϕ sideband region (green box)
  - ✓ $|M_{\pi^+\pi^-\pi^0} - M_\omega| \leq 40\ \mathrm{MeV}/c^2$ and $|M_{K^+K^-} - M_\phi\ - 45| \leq 15\ \mathrm{MeV}/c^2$
- corner region (black box)
  - ✓ $|M_{\pi^+\pi^-\pi^0} - M_\omega \pm 120| \leq 40\ \mathrm{MeV}/c^2$ and $|M_{K^+K^-} - M_\phi\ - 45| \leq 15\ \mathrm{MeV}/c^2$



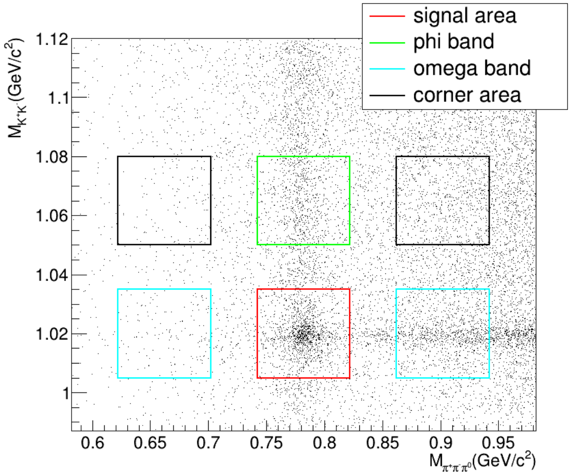
$\omega - \phi$ 2-D distribution in data

2D-sideband method

- The number of estimated background in signal area which comes from sideband contribution is calculated by:
  - ✓ $N_{bkg} = f_{\omega} \times N(cyanbox) + f_{\phi} \times N(greenbox) - f_{corner} \times N(blackbox)$

  The $N(cyanbox)$, $N(greenbox)$ and $N(blackbox)$

  is the event number in the corresponding box.



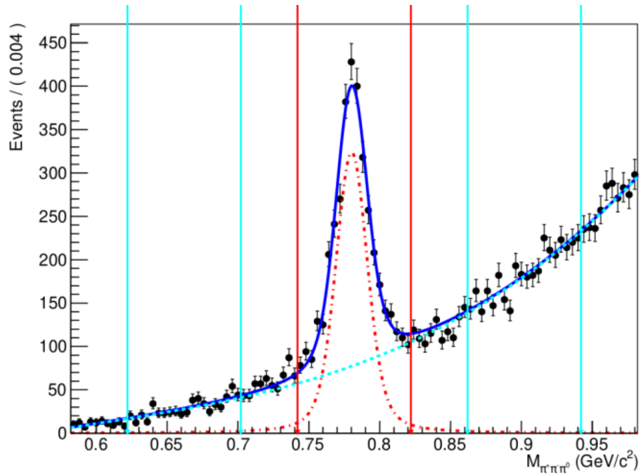
calculation of f_ω, f_ϕ from 1-D fit

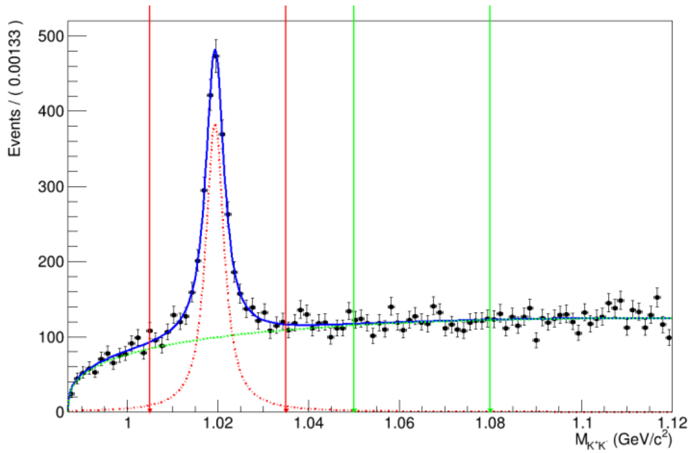
- f_ω, f_ϕ and f_{corenr} is calculated after fitting by:

$$f_\omega = N_{bkg}(redregion)/N_{bkg}(cyanregion)$$

$$f_\phi = N_{bkg}(redregion)/N_{bkg}(greenregion)$$

$$f_{corner} = f_\omega \times f_\phi$$





- fit method:
  - ✓ BW Function ⊗ Gaussian + Chebyshev polynomial
  - ✓ $f_\omega = N_{bkg}(redregion)/N_{bkg}(cyanregion)$

- fit method:
  - ✓ BW ⊗ Gaussian + anti-Argus
  - ✓ $f_\phi = N_{bkg}(redregion)/N_{bkg}(greenregion)$

fit result of data

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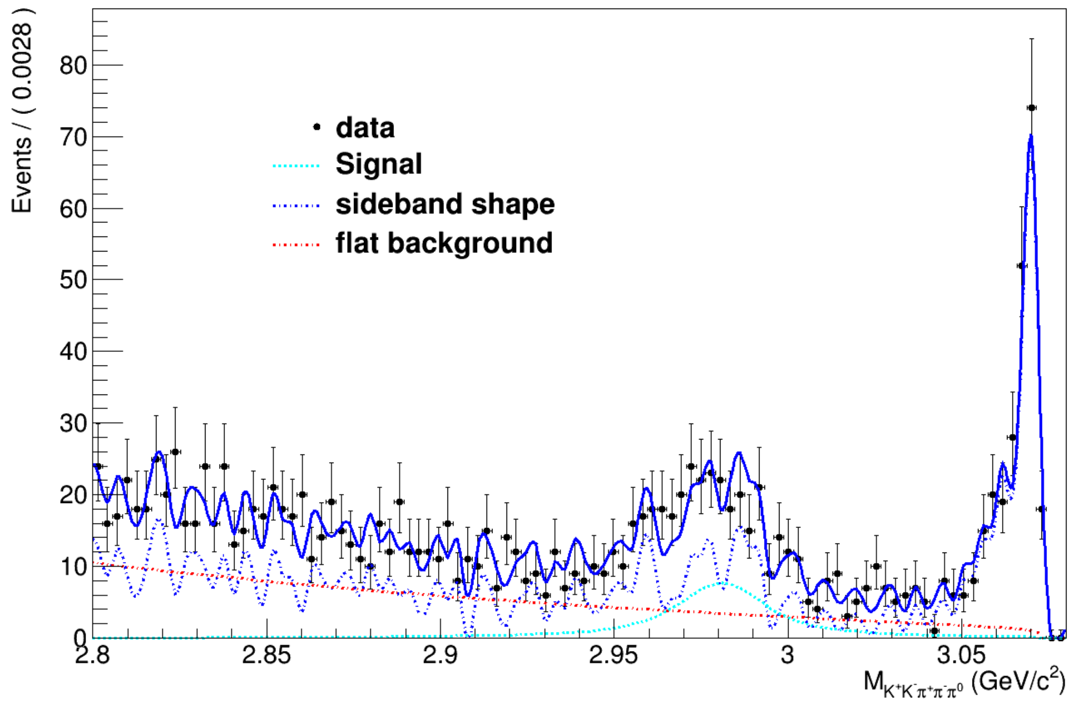

- Fit on $M_{\pi^+\pi^-\pi^0K^+K^-}$ is performed to extract signal.
- Use $N_{bkg} = f_\omega \times N(cyanbox) + f_\phi \times N(greenbox) - f_{corner} \times N(blackbox)$ to generate sideband PDF.
- Fit method:
  - ✓ Signal MC shape + sideband shape (histpdf) + Argus distribution

fit result of data

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- Preliminary fit result :
  - ✓ $N_{obs} = 120 \pm 28.50$
  - ✓ $Br(\eta_c \to \omega\phi) = \frac{N_{obs}}{\epsilon \times N_{total} \times Br(J/\psi \to \gamma\eta_c) \times Br(\omega \to \pi^+\pi^-\pi^0) \times Br(\phi \to K^+K^-) \times Br(\pi^0 \to \gamma\gamma)} = (3.20 \pm 0.76) \times 10^{-5}$
  - ✓ Significance : 4.31σ
  - ✓ (PDG upper limit: 2.5×10^{-4})

IOcheck of extracting N_{obs}

- Strategy:
  - ✓ Generate MC sample which is similar to data, and perform exactly same analysis procedure as data to this sample. And to check between extracted N_{obs}(output), and pre-known signal event number(input).
  - ✓ According to topology from inclusive MC, dominant background modes are generated to make up MC sample sample 10 times of data.

exclusive MC

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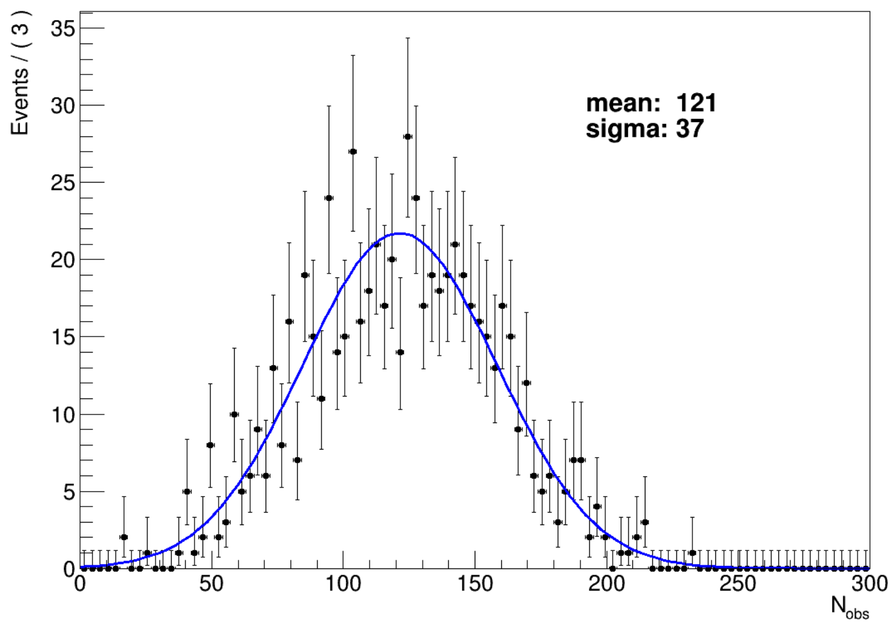
- All modes are generated based on PDG with accurate Br or referred with similar mode .

Mode
$J/\psi \to \gamma\eta_c, \eta_c \to \pi^0\pi^+\pi^-K^+K^-$
$J/\psi \to \pi^0\pi^+\pi^-K^+K^-\gamma^f$
$J/\psi \to \pi^0\pi^+\pi^-K^+K^-$
$J/\psi \to \pi^0K^*\overline{K}^*\gamma, K^* \to \pi^-K^+, \overline{K}^* \to \pi^+K^-$
$J/\psi \to \gamma\eta_c, \eta_c \to \pi^0K^*\overline{K}^*, K^* \to \pi^-K^+, \overline{K}^* \to \pi^+K^-$
$J/\psi \to \omega f_1(1420), \omega \to \pi^0\pi^+\pi^-, f_1(1420) \to \pi^0K^+K^-$
$J/\psi \to \gamma\eta_c, \eta_c \to \pi^+K^*K^{*-}, K^* \to \pi^-K^+, K^{*-} \to \pi^0K^-$
$J/\psi \to \gamma\eta_c, \eta_c \to \pi^-\overline{K}^*K^{*+}, \overline{K}^* \to \pi^+K^-, K^{*+} \to \pi^0K^+$
$J/\psi \to K_S^0K_S^0\phi, K_S^0 \to \pi^+\pi^-, K_S^0 \to \pi^0\pi^0, \phi \to K^+K^-$
$J/\psi \to \gamma\omega\phi, \omega \to \pi^0\pi^+\pi^-, \phi \to K^+K^-$

IOcheck result

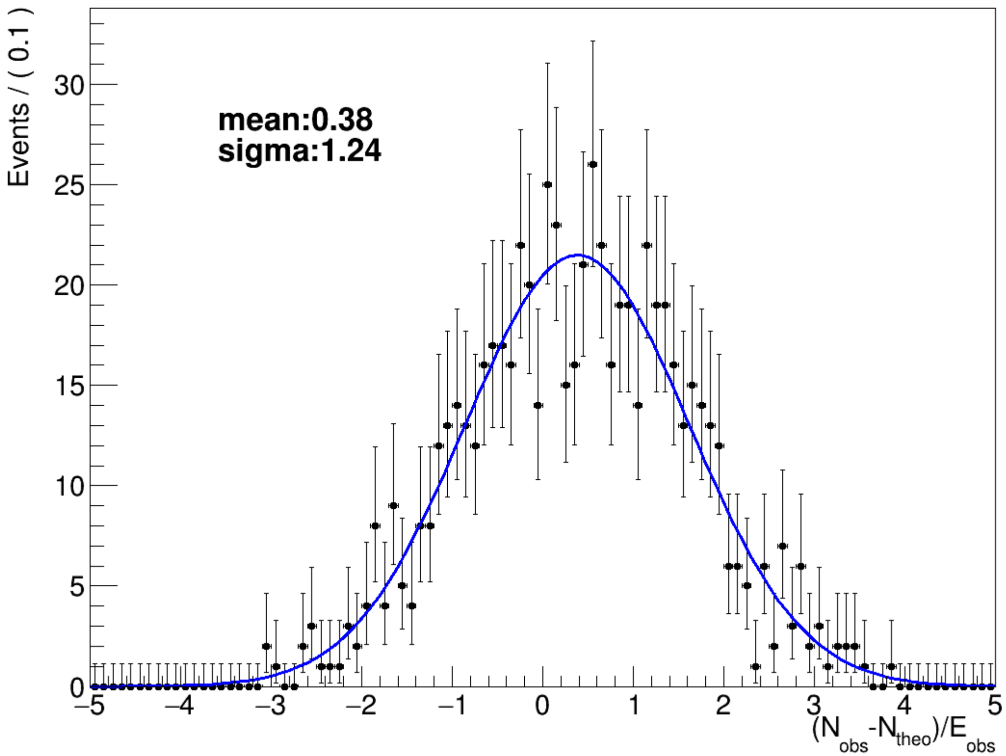
- Mix up all the exclusive MC samples and signal MC sample, and randomly sampling to generate 1000 sets of MC samples one times size of data .

- Each sample has input 110 signal event, perform the same fit procedure to get N_{obs}, fit them into a Gaussian distribution to evaluate the fit procedure.



IOcheck result

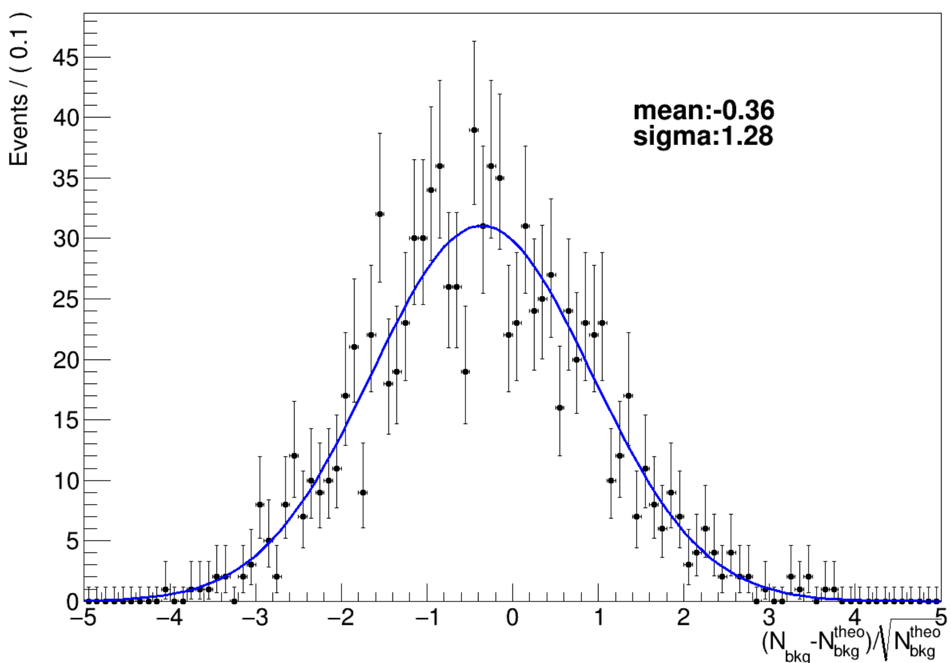
- Calculate $(N_{obs} - N_{theo})/\delta_{N_{obs}}$ to get the Pull distribution:

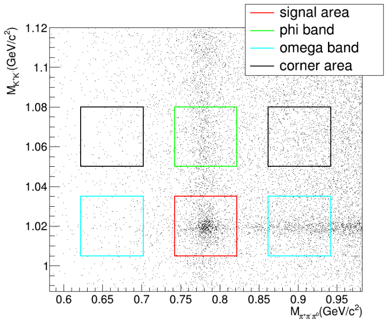


IOcheck result

- Further I check the validity of sideband method estimating background. Since each fit has its estimated sideband background contribution using $N_{bkg} = f_{\omega} \times N(cyanbox) + f_{\phi} \times N(greenbox) - f_{corner} \times N(blackbox)$.

- I preformed check between the calculated N_{bkg} and N_{bkg}^{theo}:
  - ✓ N_{bkg}^{theo}:the event number in signal area in the sample. ($\omega - \phi$ structure has been removed already.)





Thanks!

Here starts backup

Efficiency

Criteria	Events	Efficiency(%)	Relative efficiency(%)
SignalMC	2million	100	1
$N_{good} = 4 \ \&\& \ Q_{total} = 0$	615333	30.77	30.77
$N_{\gamma} \geq 3$	330554	16.53	53.72
Pass Pid	305008	15.25	92.27
Vertex Fit	303317	15.17	99.45
Pass 4C	203455	10.17	67.08
Pass 5C	196306	9.82	96.49
$2.800 \leq M_{\pi^+\pi^-\pi^0K^+K^-} \leq 3.100 GeV/c^2$	191876	9.59	97.74
$\lvert M_{\pi^+\pi^-\pi^0} - M_{\omega} \rvert \leq 40$ MeV$/c^2$	174268	8.71	90.82
$\lvert M_{K^+K^-} - M_{\phi} \rvert \leq 15$ MeV$/c^2$	162889	8.14	93.47
$\lvert \cos(\theta_{decay}) \rvert \leq 0.95$	160623	8.03	98.61
$\chi^2_{5C} \leq 20$	108613	5.43	67.62

topology from inclusive MC

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Table 1: Decay trees and their respective final states.

rowNo	decay tree	decay final state	iDcyTr	nEtr	nCEtr
1	$J/\psi \to \eta_c\gamma, \eta_c \to \pi^0\pi^+\pi^-K^+K^-$	$\pi^0\pi^+\pi^-K^+K^-\gamma$	0	104	104
2	$J/\psi \to \pi^0\pi^+\pi^-K^+K^-\gamma^f$	$\pi^0\pi^+\pi^-K^+K^-\gamma^f$	20	37	141
3	$J/\psi \to \pi^0\pi^+\pi^-K^+K^-$	$\pi^0\pi^+\pi^-K^+K^-$	14	28	169
4	$J/\psi \to \pi^0K^*\bar{K}^*\gamma, K^* \to \pi^-K^+, \bar{K}^* \to \pi^+K^-$	$\pi^0\pi^+\pi^-K^+K^-\gamma$	12	28	197
5	$J/\psi \to \omega f_1(1420), \omega \to \pi^0\pi^+\pi^-, f_1(1420) \to \pi^0K^+K^-$	$\pi^0\pi^0\pi^+\pi^-K^+K^-$	13	27	224
6	$J/\psi \to \eta_c\gamma, \eta_c \to \pi^+K^*K^{*-}, K^* \to \pi^-K^+, K^{*-} \to \pi^0K^-$	$\pi^0\pi^+\pi^-K^+K^-\gamma$	16	26	250
7	$J/\psi \to \omega f_0(980), \omega \to \pi^0\pi^+\pi^-, f_0(980) \to K^+K^-$	$\pi^0\pi^+\pi^-K^+K^-$	1	26	276
8	$J/\psi \to \eta_c\gamma, \eta_c \to \pi^-\bar{K}^*K^{*+}, \bar{K}^* \to \pi^+K^-, K^{*+} \to \pi^0K^+$	$\pi^0\pi^+\pi^-K^+K^-\gamma$	9	15	291
9	$J/\psi \to K^0_SK^0_S\phi, K^0_S \to \pi^0\pi^0, K^0_S \to \pi^+\pi^-, \phi \to K^+K^-$	$\pi^0\pi^0\pi^+\pi^-K^+K^-$	32	13	304
10	$J/\psi \to \eta_c\gamma, \eta_c \to \pi^0K^*\bar{K}^*, K^* \to \pi^-K^+, \bar{K}^* \to \pi^+K^-$	$\pi^0\pi^+\pi^-K^+K^-\gamma$	46	13	317

exclusive MC generate detail

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Mode	Note
$J/\psi \to \gamma\eta_c, \eta_c \to \pi^0\pi^+\pi^-K^+K^-$	Accurate Br in PDG
$J/\psi \to \pi^0\pi^+\pi^-K^+K^-\gamma^f$	Generated within the mode next line
$J/\psi \to \pi^0\pi^+\pi^-K^+K^-$	Accurate Br in PDG
$J/\psi \to \pi^0K^*\bar{K}^*\gamma,\ K^* \to \pi^-K^+, \bar{K}^* \to \pi^+K^-$	Referred by jpsi to gamma eta(1405/1475) to gammakkbarpi
$J/\psi \to \gamma\eta_c, \eta_c \to \pi^0K^*\bar{K}^*, K^* \to \pi^-K^+, \bar{K}^* \to \pi^+K^-$	Mode:Eta_c to kkbar pi. neutral:charged=1:2
$J/\psi \to \omega f_1(1420), \omega \to \pi^0\pi^+\pi^-, f_1(1420) \to \pi^0K^+K^-$	In PDG, Br of f1->kkbarpi is "seen"
$J/\psi \to \gamma\eta_c, \eta_c \to \pi^+K^*K^{*-}, K^* \to \pi^-K^+, K^{*-} \to \pi^0K^-$	Mode:Eta_c to kkbar pi. neutral:charged=1:2
$J/\psi \to \gamma\eta_c, \eta_c \to \pi^-\bar{K}^*K^{*+}, \bar{K}^* \to \pi^+K^-, K^{*+} \to \pi^0K^+$	Mode:Eta_c to kkbar pi. neutral:charged=1:2
$J/\psi \to K_S^0K_S^0\phi, K_S^0 \to \pi^+\pi^-, K_S^0 \to \pi^0\pi^0, \phi \to K^+K^-$	Accurate Br in PDG
$J/\psi \to \gamma\omega\phi, \omega \to \pi^0\pi^+\pi^-, \phi \to K^+K^-$	Input similar with data
$J/\psi \to \omega f_0(980), \omega \to \pi^0\pi^+\pi^-, f_0(980) \to K^+K^-$	It effects our bkg estimate badly, and in PDG the Br of f0->kkbar is "seen". Luckily there is no obvious f0 structure in data, so there is no other way but assume such mode doesn't exsist.
$J/\psi \to \gamma\eta_c, \eta_c \to \omega\phi, \omega \to \pi^0\pi^+\pi^-, \phi \to K^+K^-$	Input similar with data

try using keyspdf to describe sideband shape

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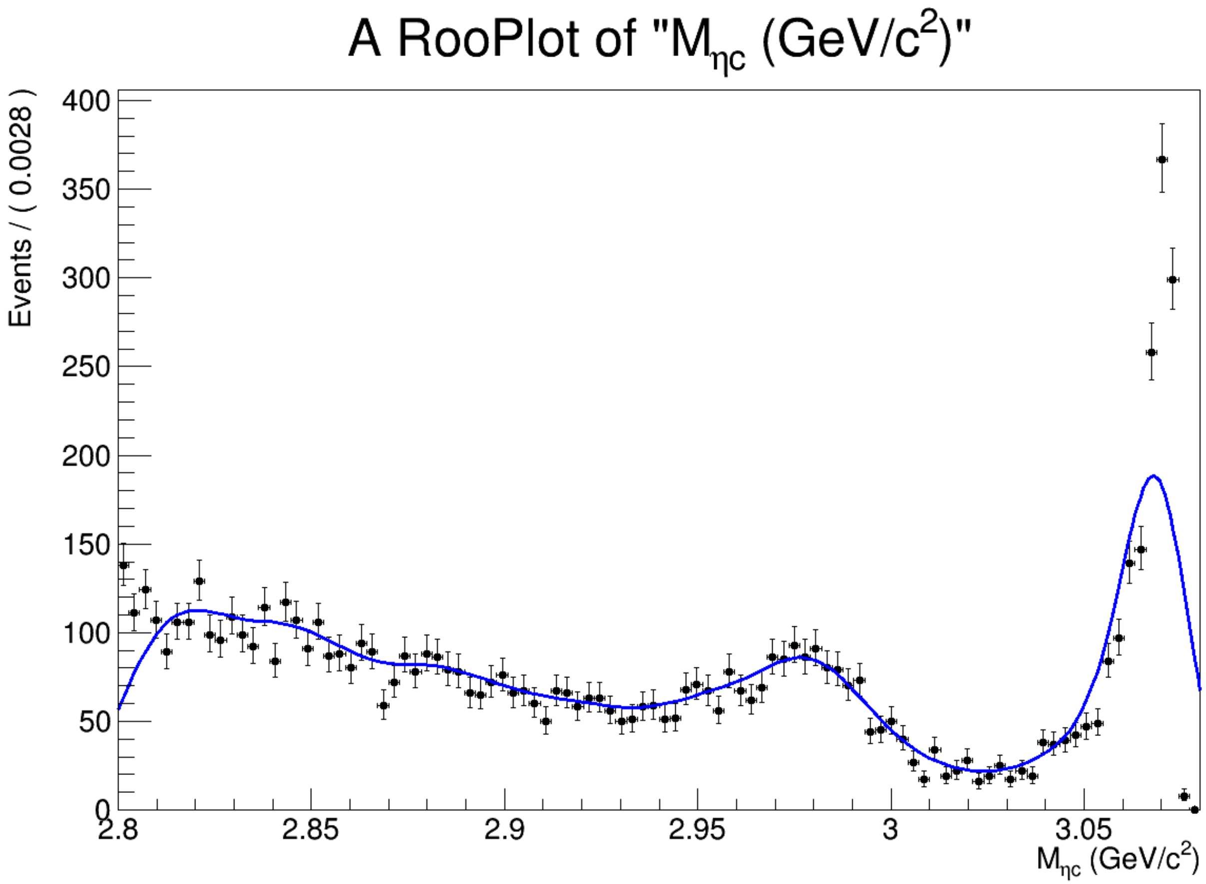
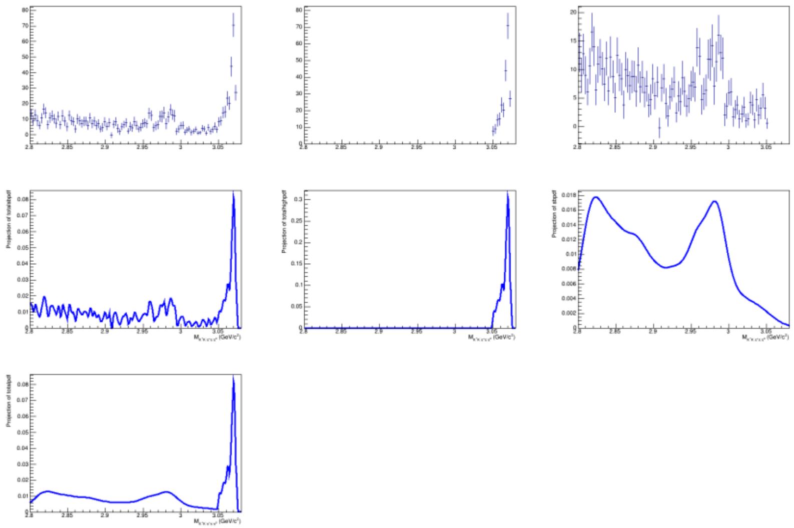


Trying to make the fit looks better



Artificially divide the dataset into two part, use histpdf and keyspdf respectively, at last connect them together.
But it doesn't work since the connected area is not smooth.

```
**********
**    8 **SET PRINT           1
**********
**********
**    9 **HESSE        2500
**********
COVARIANCE MATRIX CALCULATED SUCCESSFULLY
FCN=-11202.1 FROM HESSE     STATUS=OK             35 CALLS         711 TOTAL
                    EDM=6.17183e-05    STRATEGY= 1      ERROR MATRIX ACCURATE
 EXT PARAMETER                                INTERNAL      INTERNAL
 NO.   NAME      VALUE            ERROR       STEP SIZE       VALUE
  1  m0a        3.07197e+00   1.54453e-05   2.11291e-04  -1.05294e+00
  2  nbkgargus   4.93565e+02   4.11079e+01   2.87910e-03  -5.31045e-01
  3  nsig        1.08980e+02   2.72568e+01   6.40855e-03   8.99249e-02
  4  p1          9.99996e+00   1.58225e+00   4.16064e-02   1.56794e+00
  5  p2          9.66942e-02   1.70287e-01   1.33285e-03   3.22370e-02
                               ERR DEF= 0.5
EXTERNAL ERROR MATRIX.    NDIM=  25    NPAR=  5    ERR DEF=0.5
 2.386e-10 -6.510e-05  4.914e-05  2.355e-09  5.650e-07
-6.510e-05  1.691e+03 -5.896e+02 -1.731e-03 -3.220e+00
 4.914e-05 -5.896e+02  7.623e+02 -7.510e-04  2.477e+00
 2.355e-09 -1.731e-03 -7.510e-04  2.647e-04  1.374e-04
 5.650e-07 -3.220e+00  2.477e+00  1.374e-04  2.903e-02
PARAMETER  CORRELATION COEFFICIENTS
      NO.  GLOBAL      1      2      3      4      5
       1  0.21474   1.000 -0.102  0.115  0.009  0.215
       2  0.56370  -0.102  1.000 -0.519 -0.003 -0.460
       3  0.61247   0.115 -0.519  1.000 -0.002  0.526
       4  0.06046   0.009 -0.003 -0.002  1.000  0.050
       5  0.58974   0.215 -0.460  0.526  0.050  1.000
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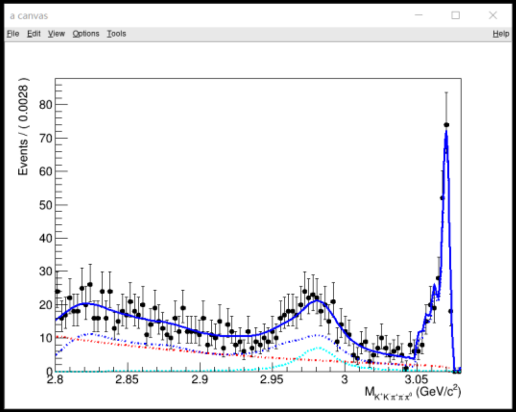

check of difference between nbkg and nbkgtheo