Study of $\chi_{cJ} \to \omega\phi\eta$ through $\psi(2S) \to \gamma\chi_{cJ}$

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Outline

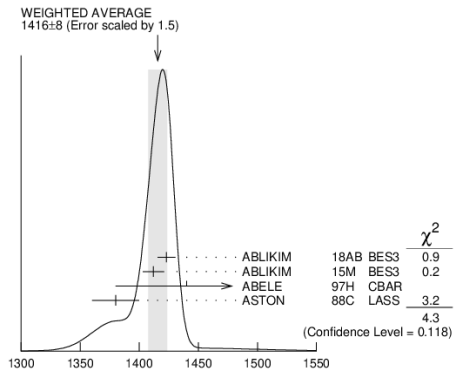
What's $h_1(1415)[h_1(1380)]$

- Axial-vector $s\bar{s}$ ground state

$h_1(1415)$ MASS — 1416 ± 8 MeV (S = 1.5)

VALUE (MeV)	*EVTS*	*DOCUMENT ID*		*TECN*	*COMMENT*
1416 ± 8	**OUR AVERAGE** Error includes scale factor of 1.5.				See the ideogram below.
$1423 \pm 2.1 \pm 7.3$	2.2k	[1] ABLIKIM	2018AB	BES3	$J/\psi \to \eta' h_1 \to \eta' K^* \overline{K}$
$1412 \pm 4 \pm 8$		[1] ABLIKIM	2015M	BES3	$\psi(2S) \to \gamma\chi_{c1,2} \to \gamma\phi(h_1 \to K^* \overline{K})$
1440 ± 60		ABELE	1997H	CBAR	$\overline{p}\,p \to K_L^0\, K_S^0\, \pi^0\pi^0$
1380 ± 20		ASTON	1988C	LASS	11 $K^-\, p \to K_S^0\, K^\pm\pi^\mp\Lambda$

[1] Final states $K^+K^-\pi^0$ and $K_S^0\, K^\pm\pi^\mp$.

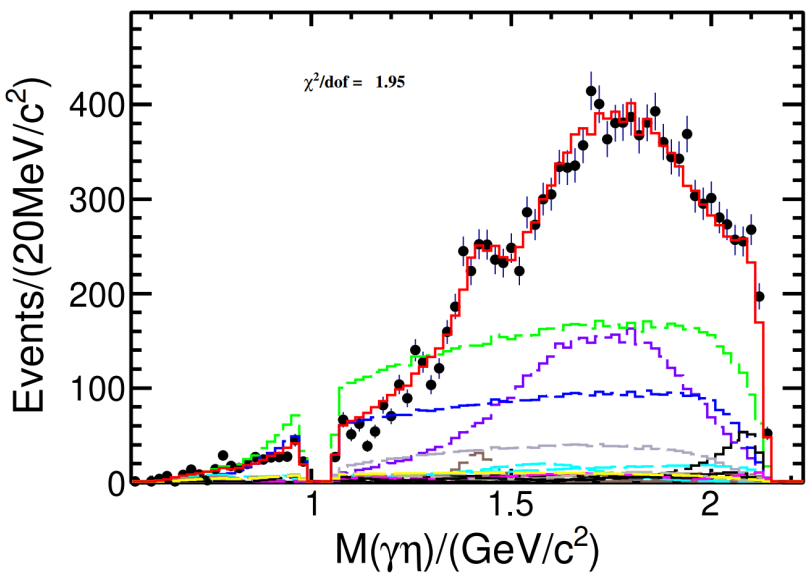


$h_1(1415)$ MASS (MeV)

References:

ABLIKIM 2018AB	PR D98 072005	Observation of $h_1(1380)$ in the $J/\psi \to \eta' K\bar{K}\pi$ decay
ABLIKIM 2015M	PR D91 112008	Study of χ_{cJ} Decaying into $\phi K^*(892)K^-$
ABELE 1997H	PL B415 280	Antiproton Proton Annihilations at Rest into K_L^0 $K_S^0\,\pi^0\pi^0$
ASTON 1988C	PL B201 573	Evidence for Two Strangeonium Resonances with $J^{PC} = 1++$ and $1+^-$ in K^-p Interactions at 11 GeV/c

BAM-00447 $J/\psi \to \gamma\eta\eta'$



$h_1 \to K^*(892)K$ is suppressed by phase-space, but all previous h1 come from K^*K final states

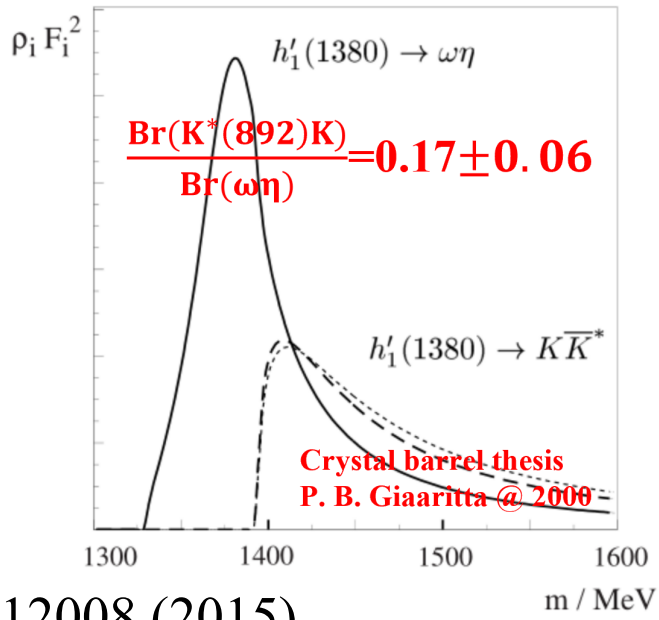
Axial-vector state? Triangle singularity? Structure generated dynamically?

New decay mode: $\gamma\eta$, any more?

Research status of $h_1(1415)[h_1(1380)]$

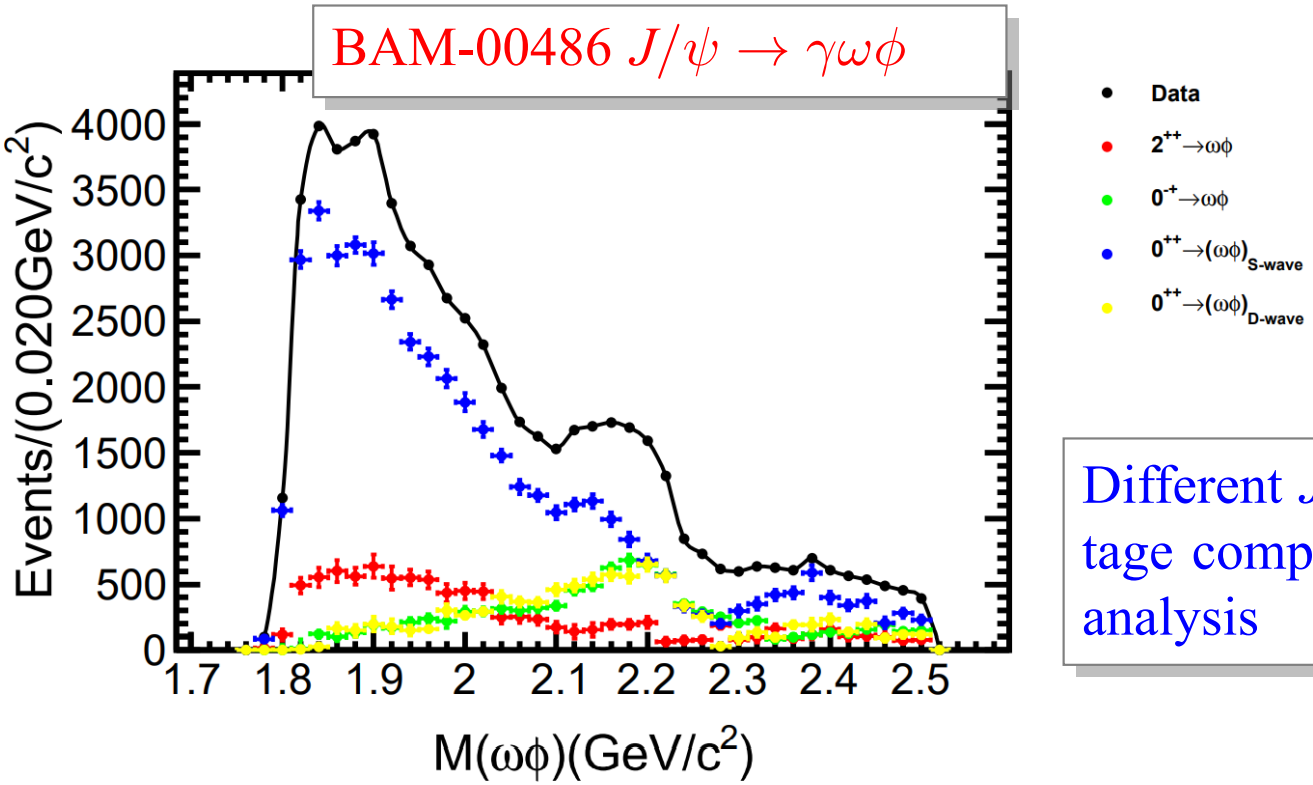
hep-ph/0007199

Mode	Wave	Width
K^*K †	S	137 ± 12
	D	1 ± 1
	D/S	$0.010^{+0.008}_{-0.004}$
$\rho\pi$	S	12 ± 3 (13)
	D	4 ± 3 (4)
	D/S	$0.4^{+0.4}_{-0.2}$ (0.4)
$\omega\eta$	S	2 ± 1 (2)
	D	0 (0)
	D/S	$0.01^{+0.01}_{-0.00}$ (0.01)
$b_1\pi$ †	P	0
Total		156



- ✓ $h_1(1415)$ @$\chi_{cJ} \to \phi K^* K$ BESIII PRD 91, 112008 (2015)
- ? $h_1(1415)$ @$\chi_{cJ} \to \phi\omega\eta$
  - * if any ω^* or ϕ^* for $\omega\eta$ system or $\phi\eta$ system?
  - ✓ $\chi_{cJ} \to \phi\omega$, $\chi_{cJ} \to \phi\phi$ BESIII PRL 107, 092001 (2011)
  - ? $\chi_{cJ} \to \phi^*\omega$, $\chi_{cJ} \to \phi\omega^*$

Vector-Vector system: $\phi\omega$



Different J^{PC} of χ_{cJ} is an advantage compared with $J/\psi(\psi(2S))$ analysis

- In $J/\psi \to \gamma\omega\phi$, especially at threshold region, dominant contribution comes from $0^{++}(S-wave)\ \omega\phi$ system, little one from 0^{-+} or 2^{++}
- If $\chi_{c0} \to \omega\phi\eta$, $0^{-+}(S)$ is allowed and $0^{++}, 2^{++}$ is impossible, contrary to J/ψ analysis.
- If $\chi_{c1} \to \omega\phi\eta$, $0^{++}(P), 2^{++}(P\ or\ F)$ is allowed, similar to J/ψ analysis.
- If $\chi_{c2} \to \omega\phi\eta$, $0^{-+}(D), 2^{++}(P\ or\ F)$ is allowed.

Data sets

- Boss version: 707
- Experimental data: 2021 $\psi(2S)$ data
- Signal MC sample: 0.1M generated by KKMC

Process	Generator
$\psi(2S) \to \gamma\chi_{cJ}$	P2GCJ
$\chi_{cJ} \to \omega\eta\phi$	PHSP
$\omega \to \pi^+\pi^-\pi^0$	OMEGA DALITZ
$\phi \to K^+K^-$	VSS
$\eta \to \gamma\gamma$	PHSP
$\eta \to \gamma\gamma$	PHSP

- Inclusive MC sample: 2009+2012 $\psi(2S)$ MC
* Final states: $K^+K^-\pi^+\pi^-\gamma\gamma\gamma\gamma$

Event selection

- Final states: $K^+K^-\pi^+\pi^-\gamma\gamma\gamma\gamma$

Charged Tracks

- $N_{charged} = 4$
- $N_+ = N_-, Q_{total} = 0$
- $|cos\theta| < 0.93$
- $V_{xy} < 1\ cm, V_z < 10\ cm$

Neutral Tracks

- $E_{barrel} \geq 25MeV, E_{endcap} \geq 50MeV$
- $0 \leq TDC \leq 70ns$
- $N_\gamma \geq 5$

PID

- $\pi : p(\pi) > p(K)$
- $K : p(K) > p(\pi)$
- $N_\pi = N_K = 2$

Vertex Fit

- Vertex fit for $K^\pm\pi^\mp$

Kinematic Fit

- 4C for $K^+K^-\pi^+\pi^-\gamma\gamma\gamma\gamma$

Event selection

* Deal with one event with more photons:
  Loop all combination and select smallest one as one candidate.
  - $\chi_{4C}(5\gamma) < \chi_{4C}(6\gamma)$ is required.
* $\pi^0\eta$ reconstruction:

- $\chi^2_{\pi^0\eta} = \frac{(M_{\gamma_1\gamma_2}-M_{\pi^0})^2}{(\sigma_{\pi^0})^2} + \frac{(M_{\gamma_3\gamma_4}-M_{\eta})^2}{(\sigma_{\eta})^2}$
- $\chi^2_{\pi^0\pi^0} = \frac{(M_{\gamma_1\gamma_2}-M_{\pi^0})^2}{(\sigma_{\pi^0})^2} + \frac{(M_{\gamma_3\gamma_4}-M_{\pi^0})^2}{(\sigma_{\pi^0})^2}$
- $\chi^2_{\eta\eta} = \frac{(M_{\gamma_1\gamma_2}-M_{\eta})^2}{(\sigma_{\eta})^2} + \frac{(M_{\gamma_3\gamma_4}-M_{\eta})^2}{(\sigma_{\eta})^2}$

- $\chi^2_{\pi^0\eta} < \chi^2_{\pi^0\pi^0}$ is required.
- $\chi^2_{\pi^0\eta} < \chi^2_{\eta\eta}$ is required.

Event selection

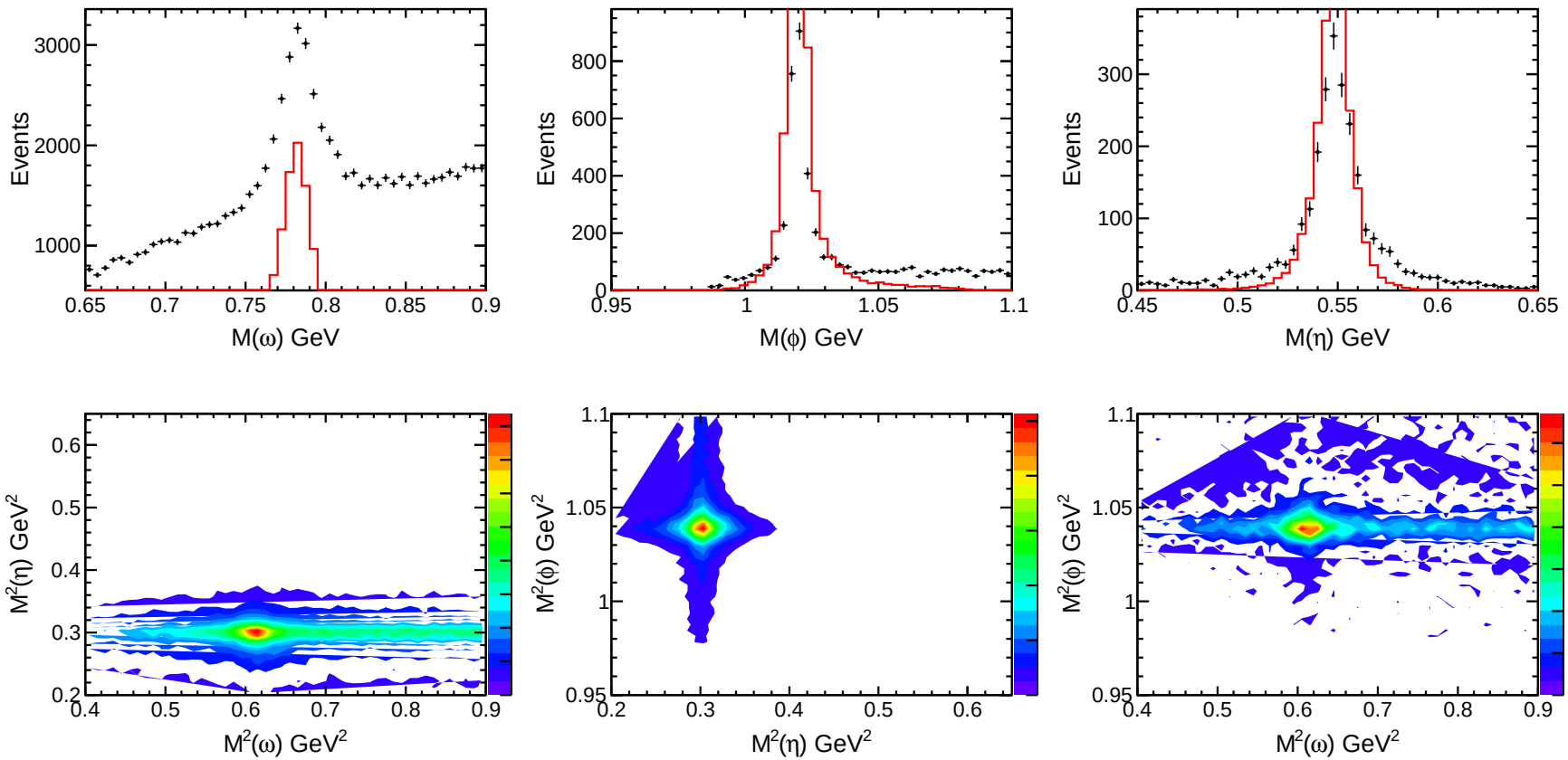
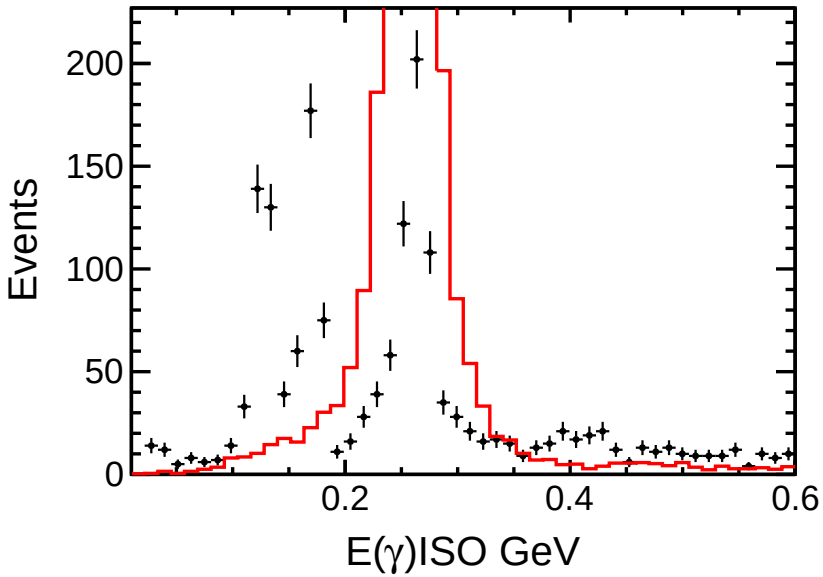
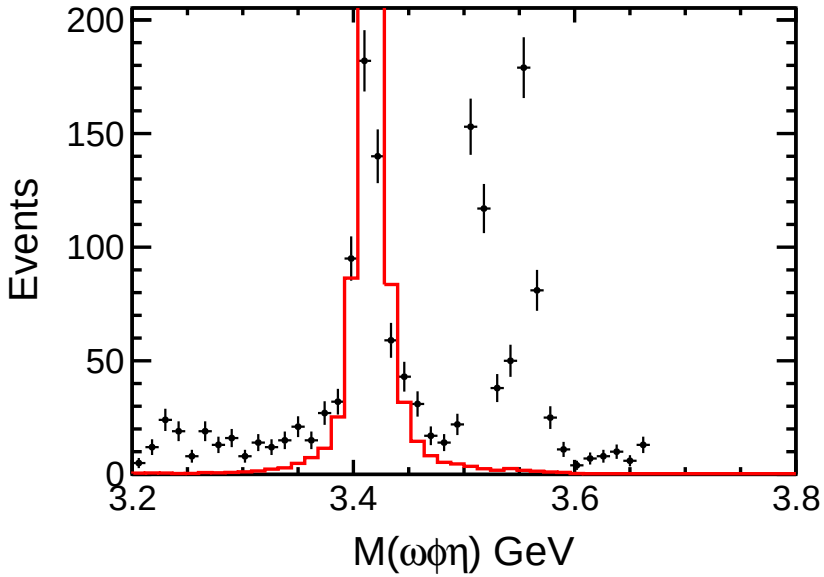


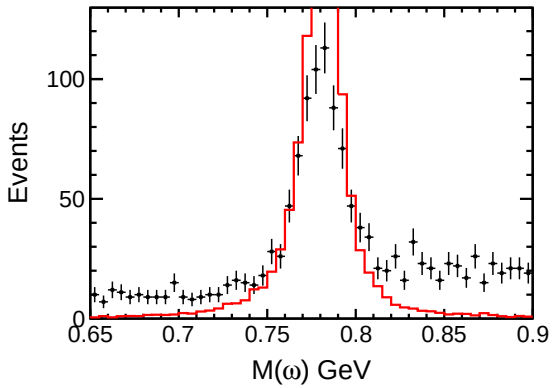
Figure: Mass distribution

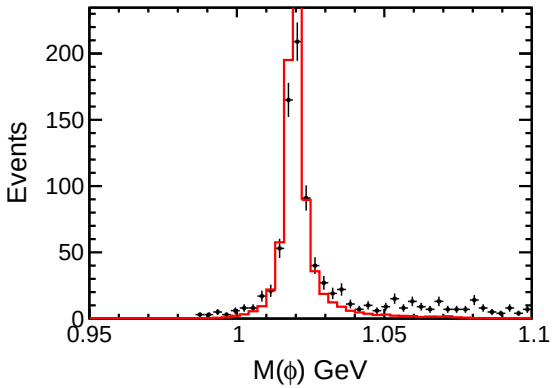
Event selection

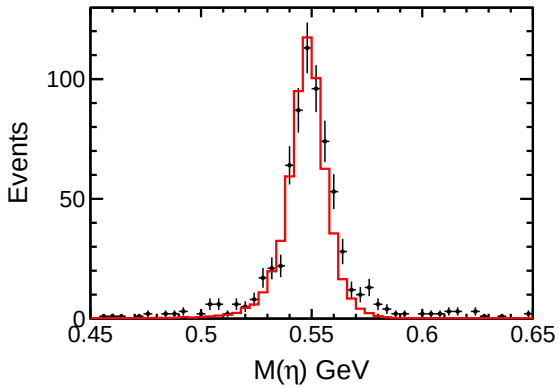
- χ_{c0} region: $3.374\ GeV < M_{\omega\eta\phi} < 3.454\ GeV$











Background analysis

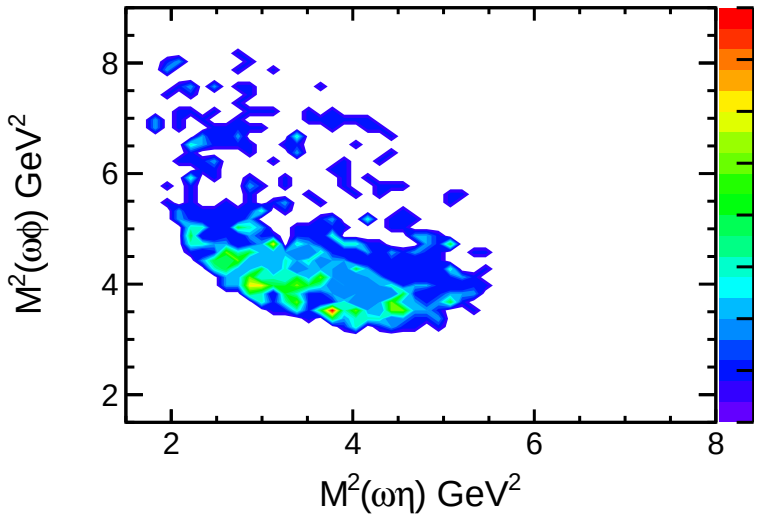
- $\chi_{c0} \to \omega\eta\phi$

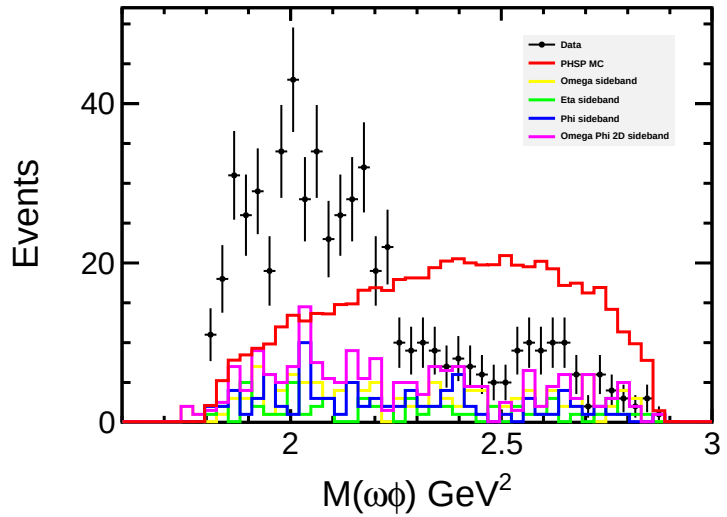
rowNo	decay tree (decay initial-final states)	iDcyTr	iDcyIFSts	nEtr	nCEtr
1	$x \to e^- Z0, Z0 \to c\bar{c}, c\bar{c} \to cluster, cluster \to \psi', \psi' \to \pi^0\pi^0 J/\psi, J/\psi \to \pi^0\pi^+\pi^- K^+K^-$ $(x \dashrightarrow e^-\pi^0\pi^0\pi^0\pi^+\pi^- K^+K^-)$	1	0	14	14
2	$x \to e^- Z0, Z0 \to c\bar{c}, c\bar{c} \to cluster, cluster \to \psi', \psi' \to \chi_{c1}\gamma, \chi_{c1} \to J/\psi\gamma,$ $J/\psi \to \pi^0\pi^+\pi^- K^+K^-$ $(x \dashrightarrow e^-\pi^0\pi^+\pi^- K^+K^-\gamma\gamma)$	3	2	5	19
3	$x \to e^- Z0, Z0 \to c\bar{c}, c\bar{c} \to cluster, cluster \to \psi', \psi' \to \chi_{c1}\gamma, \chi_{c1} \to \rho^- \bar{K}^* K^{*+},$ $\rho^- \to \pi^0\pi^-, \bar{K}^* \to \pi^+ K^-, K^{*+} \to \pi^0 K^+$ $(x \dashrightarrow e^-\pi^0\pi^0\pi^+\pi^- K^+K^-\gamma)$	2	1	2	21
4	$x \to e^- Z0, Z0 \to c\bar{c}, c\bar{c} \to cluster, cluster \to \psi', \psi' \to \pi^0\pi^+ K^* K^{*-}, K^* \to \pi^- K^+,$ $K^{*-} \to \pi^0 K^-$ $(x \dashrightarrow e^-\pi^0\pi^0\pi^+\pi^- K^+K^-)$	14	5	2	23
5	$x \to e^- Z0, Z0 \to c\bar{c}, c\bar{c} \to cluster, cluster \to \psi', \psi' \to \bar{K}^* K^{*+} b_1^-, \bar{K}^* \to \pi^+ K^-,$ $K^{*+} \to \pi^0 K^+, b_1^- \to \pi^-\omega, \omega \to \pi^0\gamma$ $(x \dashrightarrow e^-\pi^0\pi^0\pi^+\pi^- K^+K^-\gamma)$	16	1	2	25
6	$x \to e^- Z0, Z0 \to c\bar{c}, c\bar{c} \to cluster, cluster \to \psi', \psi' \to \pi^+\pi^- J/\psi, J/\psi \to \pi^0\pi^0 K^+K^-$ $(x \dashrightarrow e^-\pi^0\pi^0\pi^+\pi^- K^+K^-)$	19	5	2	27
7	$x \to e^- Z0\gamma^F, Z0 \to c\bar{c}, c\bar{c} \to cluster, cluster \to \psi', \psi' \to \pi^0\pi^+ K^* K^{*-}, K^* \to \pi^- K^+,$ $K^{*-} \to \pi^0 K^-$ $(x \dashrightarrow e^-\pi^0\pi^0\pi^+\pi^- K^+K^-\gamma^F)$	22	9	2	29
8	$x \to e^- Z0\gamma^F, Z0 \to c\bar{c}, c\bar{c} \to cluster, cluster \to \psi', \psi' \to \pi^+\pi^- J/\psi, J/\psi \to \pi^0 K^- K^{*+},$ $K^{*+} \to \pi^0 K^+$ $(x \dashrightarrow e^-\pi^0\pi^0\pi^+\pi^- K^+K^-\gamma^F)$	29	9	2	31
9	$x \to e^- Z0, Z0 \to c\bar{c}, c\bar{c} \to cluster, cluster \to \psi', \psi' \to \pi^0\pi^0 J/\psi, J/\psi \to \eta K^* \bar{K}^*,$ $\eta \to \gamma\gamma, K^* \to \pi^- K^+, \bar{K}^* \to \pi^+ K^-$ $(x \dashrightarrow e^-\pi^0\pi^0\pi^+\pi^- K^+K^-\gamma\gamma)$	33	3	2	33
10	$x \to e^- Z0, Z0 \to c\bar{c}, c\bar{c} \to cluster, cluster \to \psi', \psi' \to \pi^0\pi^0 J/\psi, J/\psi \to \pi^- \bar{K}^* K^{*+},$ $\bar{K}^* \to \pi^+ K^-, K^{*+} \to \pi^0 K^+$ $(x \dashrightarrow e^-\pi^0\pi^0\pi^0\pi^+\pi^- K^+K^-)$	35	0	2	35
11	$x \to e^- Z0\gamma^F, Z0 \to c\bar{c}, c\bar{c} \to cluster, cluster \to \psi', \psi' \to \pi^0\pi^0 J/\psi, J/\psi \to \pi^0\pi^+\pi^- K^+K^-$ $(x \dashrightarrow e^-\pi^0\pi^0\pi^0\pi^+\pi^- K^+K^-\gamma^F)$	39	14	2	37
12	$x \to e^- Z0, Z0 \to c\bar{c}, c\bar{c} \to cluster, cluster \to \psi', \psi' \to \pi^0\pi^0 J/\psi, J/\psi \to \pi^+ K^* K^{*-},$ $K^* \to \pi^- K^+, K^{*-} \to \pi^0 K^-$ $(x \dashrightarrow e^-\pi^0\pi^0\pi^0\pi^+\pi^- K^+K^-)$	45	0	2	39

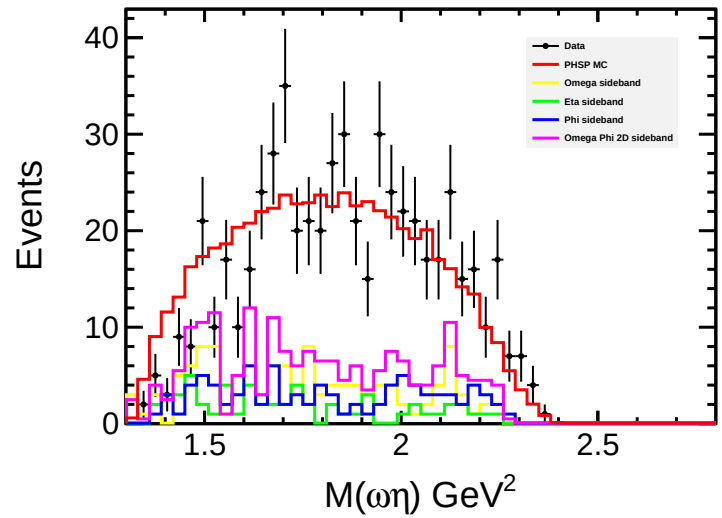
Figure: Topology analysis

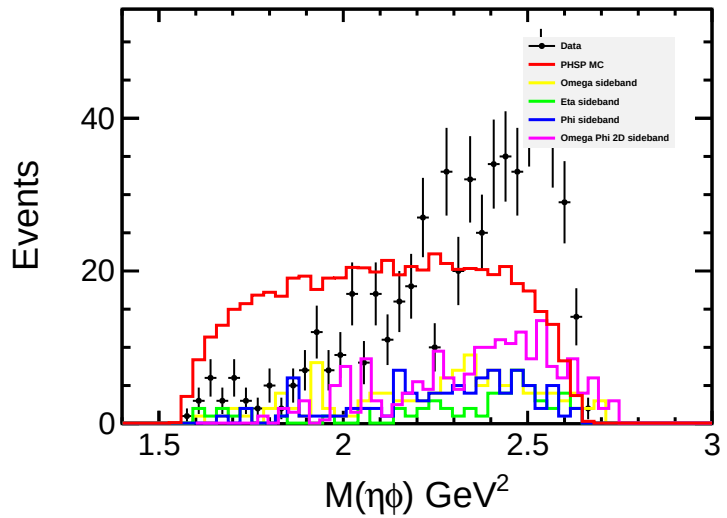
Mass distribution

- χ_{c0} region: $3.374\ GeV < M_{\omega\eta\phi} < 3.454\ GeV$









Summary

✓ Event selection for $\chi_{c0} \to \omega\eta\phi$ has been studied with new 2021 $\psi(2S)$ data.

? Seems to have some structure.

Next to do

- More background analysis
- χ_{c1}, χ_{c2} analysis.
- Plan to move on PWA for $\chi_{cJ} \to \omega\eta\phi$