Status report on phase study $(\psi(2S), J/\psi) \to \Sigma^{\circ}\bar{\Sigma}^{\circ}$ and $(\psi(2S), J/\psi) \to \Sigma^{+}\bar{\Sigma}^{-}$ decays

Group Meeting

August 2, 2021

Outline

J/ψ Phase Scan – Real Data

Ecm (GeV)	RunID	BEMS ECM(GeV)	$L_{int}(nb^{-1})$
3.0500	28312 – 28346	3.050206 ± 0.000026	14919 ± 161
3.0600	28347 – 28381	3.059257 ± 0.000028	15060 ± 161
3.0830	28382 – 28387, 28466 – 28469	3.083060 ± 0.000023	4769 ± 55
3.0900	28388 – 28416, 28472 – 28475	3.089418 ± 0.000022	15558 ± 165
3.0930	28417 – 28453, 28476 – 28478	3.092324 ± 0.000025	14910 ± 160
3.0943	28479 – 28482	3.095261 ± 0.000084	2143 ± 25
3.0952	28487 – 28489	3.095994 ± 0.000081	1816 ± 21
3.0958	28490 – 28492	3.096390 ± 0.000075	2135 ± 25
3.0969	28493 – 28495	3.097777 ± 0.000076	2069 ± 26
3.0982	28496 – 28498	3.098904 ± 0.000075	2203 ± 25
3.0990	28499 – 28501	3.099606 ± 0.000093	756 ± 11
3.1015	28504 – 28505	3.101923 ± 0.000106	1612 ± 21
3.1055	28506 – 28509	3.106144 ± 0.000090	2106 ± 25
3.1120	28510 – 28511	3.112615 ± 0.000093	1720 ± 21
3.1200	28512 – 28513	3.120442 ± 0.000115	1264 ± 16

B.X. Zhang, Luminosity measurement for J/psi phase and lineshape study

- **Energy shift:** Correct the BEMS with energy shift **-0.548 MeV**
- **Analysis Environment:** **BOSS 6.6.4.p01**
- **MC Samples:** MC generated by DIY model with ConExc

Event number and Cross sections @ 15 Energy points

Energy (GeV)	$N^{sig.}$	$\epsilon(\%)$	BF(%)	$\mathcal{L}\,(\mathrm{pb}^{-1})$	Cross section (pb)
3.0500	19.7 ± 6.0	37.6	63.9	$14.895 \pm 0.029 \pm 0.165$	$2.75 \pm 0.83 \pm 0.20$
3.0600	15.8 ± 5.3	37.8	63.9	$15.056 \pm 0.030 \pm 0.168$	$2.12 \pm 0.73 \pm 0.13$
3.0830	8.0 ± 3.8	38.5	63.9	$4.759 \pm 0.017 \pm 0.053$	$3.46 \pm 1.64 \pm 0.26$
3.0900	61.4 ± 9.1	38.2	63.9	$15.552 \pm 0.030 \pm 0.172$	$8.09 \pm 1.20 \pm 0.46$
3.0930	92.0 ± 11.4	38.1	63.9	$15.249 \pm 0.030 \pm 0.169$	$12.7 \pm 1.57 \pm 0.62$
3.0943	258.8 ± 18.6	38.4	63.9	$2.145 \pm 0.011 \pm 0.025$	$245.8 \pm 17.7 \pm 12.3$
3.0952	953.4 ± 35.5	38.3	63.9	$1.819 \pm 0.010 \pm 0.021$	$1072.7 \pm 40.0 \pm 63.3$
3.0958	2623 ± 59.5	38.2	63.9	$2.161 \pm 0.011 \pm 0.029$	$2519.6 \pm 57.1 \pm 163.8$
3.0969	4402 ± 77.4	38.3	63.9	$2.097 \pm 0.011 \pm 0.03$	$4341.7 \pm 76.4 \pm 247.5$
3.0982	2209 ± 54.5	38.4	63.9	$2.210 \pm 0.012 \pm 0.031$	$2042.0 \pm 50.4 \pm 128.6$
3.0990	292.9 ± 20.1	37.9	63.9	$0.759 \pm 0.007 \pm 0.009$	$791.4 \pm 54.4 \pm 41.2$
3.1015	175.0 ± 15.3	38.0	63.9	$1.614 \pm 0.010 \pm 0.018$	$223.3 \pm 19.5 \pm 11.8$
3.1055	108.9 ± 12.4	37.6	63.9	$2.106 \pm 0.011 \pm 0.024$	$107.5 \pm 12.2 \pm 5.4$
3.1120	57.7 ± 8.9	36.0	63.9	$1.719 \pm 0.010 \pm 0.02$	$72.9 \pm 11.2 \pm 3.9$
3.1200	15.4 ± 5.0	31.9	63.9	$1.261 \pm 0.009 \pm 0.015$	$29.8 \pm 10.0 \pm 2.4$

- **The luminosities are quoted from Dr. Zhang Binxin's report on R&QCD meeting.**

Fit to $J/\psi \to \Sigma^\circ\bar{\Sigma}^\circ$ Lineshape

To Fit the Lineshape:

- The Born cross section of $e^+e^- \to \Sigma^\circ\bar{\Sigma}^\circ$is expressed as:
  $\sigma(W) = \left| D\frac{Se^{i\phi}+E}{M_{J/\psi}-W-i\Gamma_{J/\psi}/2} - C \right|^2$
- $\boldsymbol{B}_{J/\psi\to\Sigma^0\bar{\Sigma}^0} = constant \times \left|\boldsymbol{S}e^{i\phi} + \boldsymbol{E}\right|^2$
- where constant $= 1/0.3894 \times 10^9$ (pb-to- GeV^{-2} conversion factor)
- $J/\psi \to e^+e^-$ **Amplitude:** $D = \frac{\Gamma_{J/\psi}/2}{M_{J/\psi}}\sqrt{12\pi B_{J/\psi\to e^+e^-}}$

The values of the parameters S, E and C are defined as;

For Continuum Amplitude:

- $\sigma_{\rm cont}(W) = \sigma_o(\frac{W_o}{W})^{\rm pQCD} = C^2$
- $C = \sqrt{\sigma_{\rm o}(3{\rm GeV})}\left(\frac{3{\rm GeV}}{W}\right)^{\frac{p_{\rm QCD}}{2}=5}$

Electromagnetic Amplitude: EM contribution to the Feynman diagram, we look at ratio b/w B_{out} of the final state and $B_{\mu\mu}$. EM amplitude simplified as:

- $E = \sqrt{\frac{C^2}{\sigma_{e^+e^-\to\mu^+\mu^-}}B_{J/\psi\to\mu^+\mu^-}}$

Fitting Procedure

To Fit the Line-Shape: To incorporating the the effect of radiative function $F(x, W)$ and Energy Spread S_E in the fit, the dressed Born cross section is modified as;

1. Incorporating the radiative correction $F(x, W)$:
   $\sigma'(W) = \int_0^{1-\left(\frac{W_{\min}}{W}\right)^2} dx F(x, W)\sigma(W\sqrt{1-x})$
2. Energy spread S_E is included by convolving with Gaussian function by set the width of S_E. The Born cross section becomes:
   $\sigma''(W) = \int_{W-nS_E}^{W+nS_E} \frac{1}{\sqrt{2\pi}S_E} \exp\left(\frac{-\left(W-W'\right)^2}{2S_E^2}\right) \sigma'\left(W'\right) dW$

Minimization Function: The fitting parameters are obtained by means of χ^2-minimization as:

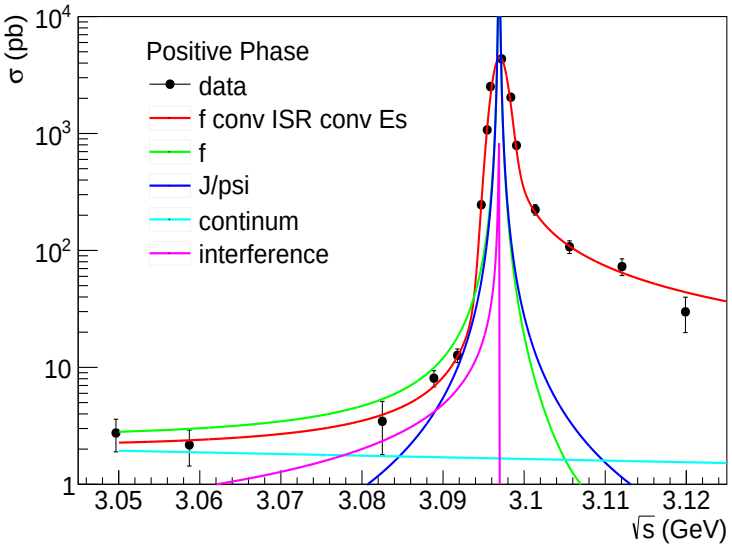
$$\chi^2_{\min} = \sum_{i=1}^{15} \frac{\left(\sigma_i^{\text{obs}} - \sigma''\left(W_i\right)\right)^2}{\left(\Delta\sigma_i^{\text{obs}}\right)^2 + \left[\left(\sigma''\left(W_i + \frac{\Delta W_i}{2}\right) - \sigma''\left(W_i - \frac{\Delta W_i}{2}\right)\right)\right]^2},$$

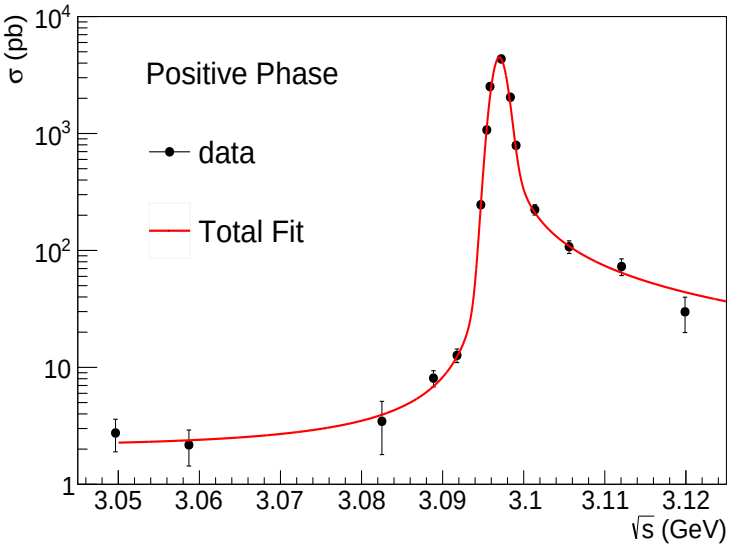
where error along X-axis, is projected along the Y-axis.

Fitting Result - Solution-I,II

- The contribution of correlated uncertainties are included in the fit.
- The fit includes both statistical and systematical uncertainty.

- **+ve phase:** $\Phi_{3g,\gamma} = (145 \pm 33.7)^\circ$
- **-ve phase:** $\Phi_{3g,\gamma} = (144.4 \pm 33.5)^\circ$



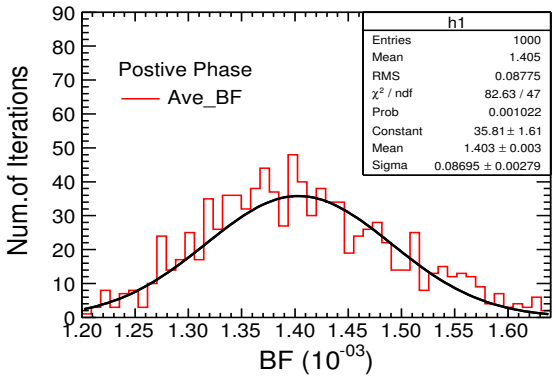


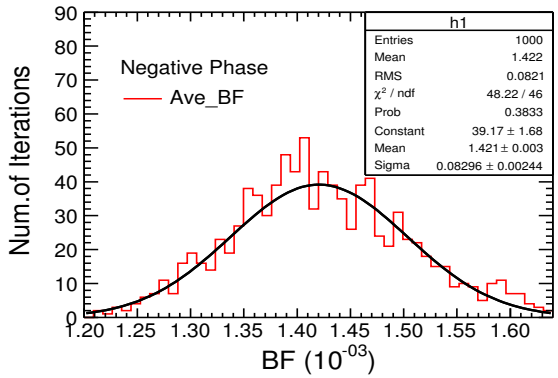
Fitting result of lineshape $J/\psi \to \Sigma^\circ\bar{\Sigma}^\circ$ with fit quality $\chi^2/nodf = 20.6/11$

Fitting Procedure - Solution-I,II

Branching Fractions:

- Since the parameters are high correlated therefore, the error in the BF($J/\psi \to \Sigma^0\bar{\Sigma}^0$) is obtained after parameterized the value of each parameter.





This Work

- **In PDG: BF =** $(1.172 \pm 0.031) \times 10^{-3}$
- **For +ve phase:** BF $=(1.403 \pm 0.086) \times 10^{-3}$
- **For -ve phase:** BF $=(1.421 \pm 0.083) \times 10^{-3}$
- Parameters are floating in fit such as; Strong, Continuum, $\Phi_{3g,\gamma}$ and S_E

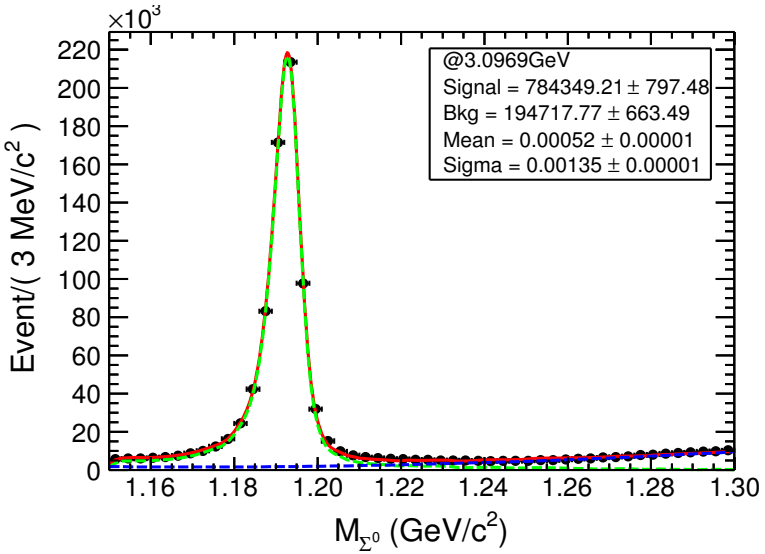
Solution	$\Delta\Phi_{3g,\gamma}(^\circ)$	SE (MeV)	BF($J/\psi \to \Sigma^0\bar{\Sigma}^0$)	χ^2/ndf
Sol-I	144.7 ± 33.7	0.885 ± 0.015	$(1.403 \pm 0.086) \times 10^{-3}$	20.6/11.0
Sol-II	-144.4 ± 33.5	0.885 ± 0.015	$(1.421 \pm 0.083) \times 10^{-3}$	20.6/11.0

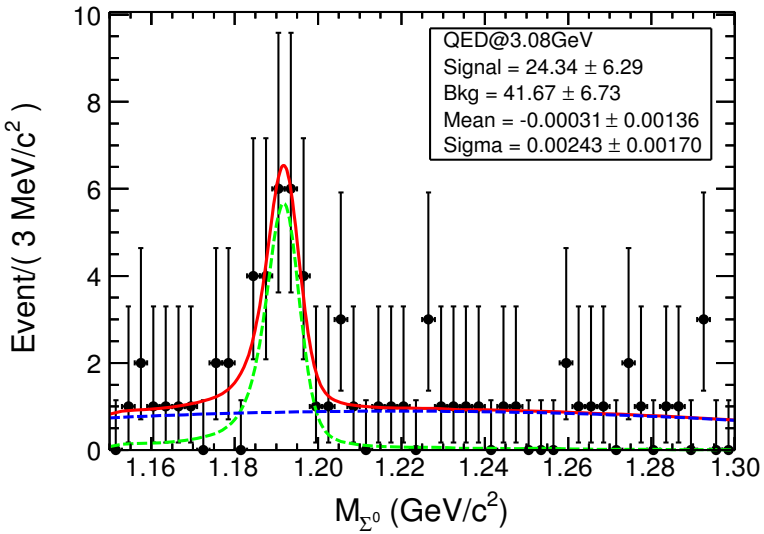
Fitting results on J/ψ lineshape from $\Sigma^0\bar{\Sigma}^0$

Cross-check → BF($J/\psi \to \Sigma^\circ\bar{\Sigma}^\circ$) (2009+2012) data

Branching Fraction cross check:

- Tested BF of $J/\psi \to \Sigma^\circ\bar{\Sigma}^\circ$ with 1312.5×10^6 sample and also estimate the QED process for J/ψ sample at $\sqrt{s} = 3.08$ GeV.





$$BF(J/\psi \to \Sigma^0\bar{\Sigma}^0) = \frac{N^{obs} - N^{bkg}}{N_{J/\psi} \cdot \epsilon \cdot BF(\Lambda \to p\pi)}$$

$$N^{bkg} = N_{3.08} \times \frac{\mathcal{L}_{J/\psi}}{\mathcal{L}_{3.08}} \times \frac{s_{3.08}}{s_{J/\psi}}$$

Using KKMC Angsam/J2BB1 $\epsilon = 38.5\%$

$$BF(J/\psi \to \Sigma^0\bar{\Sigma}^0) = (1.198 \pm 0.0022) \times 10^{-03}$$

$$BF_{PDG} = (1.172 \pm 0.031) \times 10^{-3}$$

Study the $\psi(2S)$ lineshape

$\psi(2S)$ Phase Scan – Real Data

- **$\psi(2S)$ scan data 2018**

Ecm (GeV)	RunID	Number of Run	Data taken time	$\mathcal{L}$ (pb^{-1})
3.58154	55375 – 55461	83	180505 – 180508	84.604 ± 0.082
3.67016	55462 – 55541	80	180508 – 180512	83.582 ± 0.084
3.60814	55542 – 55635	91	180512 – 180515	83.060 ± 0.083
3.68275	55636 – 55662	26	180516 – 180516	28.175 ± 0.049
3.68422	55663 – 55690	28	180517 – 180518	27.840 ± 0.048
3.68526	55691 – 55716	25	180519 – 180519	25.342 ± 0.046
3.68650	55717 – 55737	20	180519 – 180520	24.481 ± 0.045
3.69136	55738 – 55795	57	180520 – 180523	68.647 ± 0.076
3.70976	55796 – 55859	60	180523 – 180525	69.326 ± 0.077

B.X. Zhang, Luminosity measurement for $\psi(2S)$ phase and lineshape study

- **Analysis Environment:** **Under the BOSS 7.0.3**
- **MC Samples:** Generated 25k signal MC events at each energy point
- MC is generated with an angular distribution of $1 + \alpha \cos^2\theta$ for $\psi(2S) \to \Sigma^0\bar{\Sigma}^0$, by setting $\alpha = 0.71 \pm 0.12$ → Phys. Rev. D 95, 052003 (2017)

Event numbers and Cross sections @ 9 Energy points

Energy (GeV)	$N^{sig.}$	$\epsilon(\%)$	BF(%)	$\mathcal{L}\,(\mathrm{pb}^{-1})$	Cross section (pb)
3.58154	1.67 ± 3.0	31.1	63.9	84.604 ± 0.082	0.05 ± 0.09
3.67016	5.6 ± 4.0	28.2	63.9	83.582 ± 0.084	0.18 ± 0.13
3.68014	33.5 ± 7.0	27.8	63.9	83.060 ± 0.083	1.13 ± 0.24
3.68275	117 ± 11.0	27.8	63.9	28.175 ± 0.049	11.7 ± 1.1
3.68422	617.6 ± 24.6	27.3	63.9	27.840 ± 0.048	63.5 ± 2.5
3.68526	1377 ± 36.3	27.4	63.9	25.342 ± 0.046	154.9 ± 4.1
3.68650	1475 ± 37.8	27.7	63.9	24.481 ± 0.045	170.5 ± 4.4
3.69136	314.2 ± 18.5	27.6	63.9	68.647 ± 0.076	14.1 ± 0.8
3.70976	72.8 ± 10.7	27.2	63.9	69.326 ± 0.077	3.02 ± 0.5

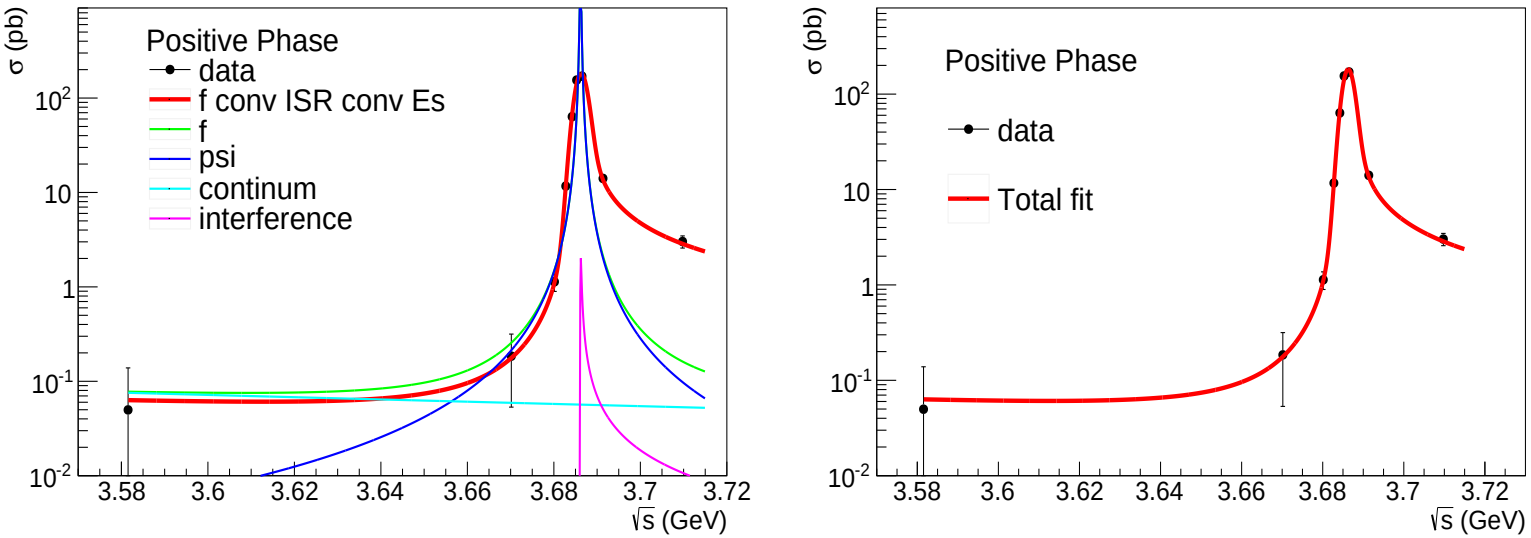
- **Fit results can be found in backup**

Prelimanry Phase Result

Fitting Result - Solution-I,II

- **Phase values:** $\Phi_{3g,\gamma} = \pm(86.6 \pm 28.0)^\circ$

Prelimanary Fit



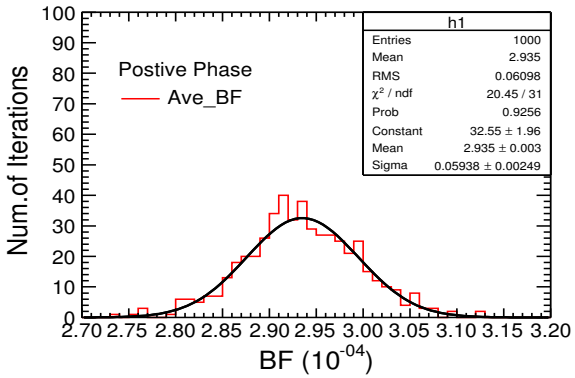
Fitting result of lineshape $\psi(2S) \to \Sigma^\circ\bar{\Sigma}^\circ$ with fit quality $\chi^2/nodf = 18.09/5.0$

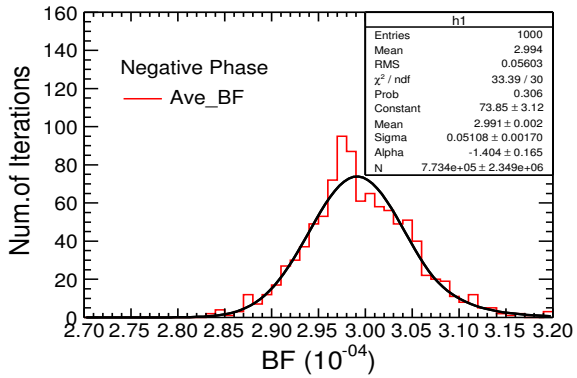
- **Current relative phase value supports the universal orthogonality b/w A_{3g} and A_γ.**

Fitting Procedure - Solution-I,II

Branching Fractions:

- Since the parameters are high correlated therefore, the error in the BF($\psi(2S) \to \Sigma^0\bar{\Sigma}^0$) is obtained after parameterized the value of each parameter.





This Work

- **In PDG: BF =** $(2.35 \pm 0.09) \times 10^{-4}$
- **For +ve phase:** BF $=(2.94 \pm 0.06) \times 10^{-4}$
- **For -ve phase:** BF $=(2.99 \pm 0.05) \times 10^{-4}$
- Parameters are floating in fit such as; Strong, Continuum, $\Phi_{3g,\gamma}$ and S_E

Solution	$\Delta\Phi_{3g,\gamma}(^\circ)$	**SE (MeV)**	**BF**$(J/\psi \to \Sigma^0\bar{\Sigma}^0)$	χ^2**/ndf**
Sol-I	86.6 ± 28.0	1.36 ± 0.026	$(2.94 \pm 0.06) \times 10^{-4}$	18.09/5.0
Sol-II	86.6 ± 28.0	1.36 ± 0.026	$(2.94 \pm 0.06) \times 10^{-4}$	18.09/5.0

Fitting results on $\psi(2S)$ lineshape from $\Sigma^0\bar{\Sigma}^0$

Problems – What Next To Do

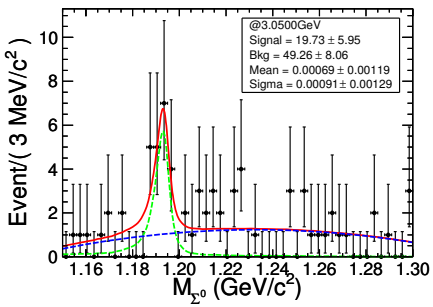
- Measured relative phase value for $J/\psi \to \Sigma^0\bar{\Sigma}^0$ is contradicted with the prediction of SU(3) spin-1/2 octet and favor to the pQCD prediction means full interference scenario.
- On contrary to that the relative phase for $\Psi(2S) \to \Sigma^0\bar{\Sigma}^0$ favors to the $\pm 90^\circ$ prediction.
- **Cross-check for BF($J/\psi \to \Sigma^0\bar{\Sigma}^0$) is performed and result is found to be consistent with PDG value.**

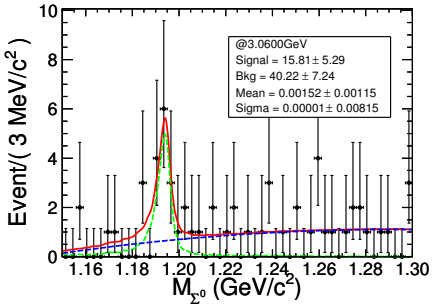
Problems and Next-to-Do:

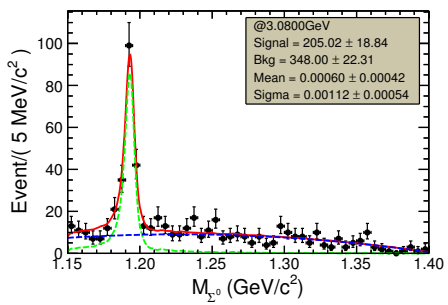
- **At present, BF($J/\psi(2S) \to \Sigma^\circ\bar{\Sigma}^\circ$) for both the analysis are deviated from PDG values.**
- Fitting lineshape function will be tested with Marco's and Yadi's lineshapes and figure out the fit biased.
- Do efficiency optimization for $\Psi(2S) \to \Sigma^0\bar{\Sigma}^0$.
- **Do systematic study for $\Psi(2S) \to \Sigma^0\bar{\Sigma}^0$ analysis.**
- Memo is being prepared for $J/\psi(2S) \to \Sigma^\circ\bar{\Sigma}^\circ$.

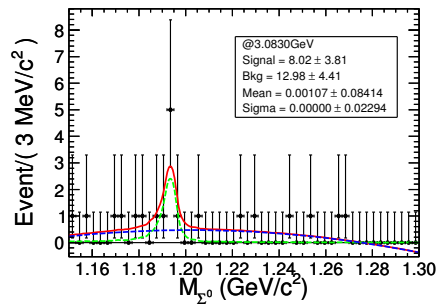
Back up

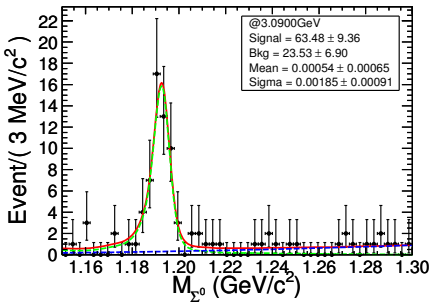
Fitting Results @15 Energy points

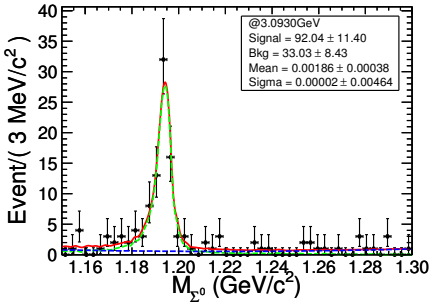


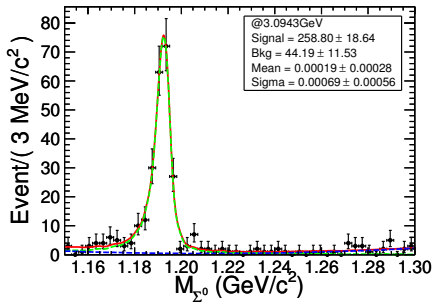


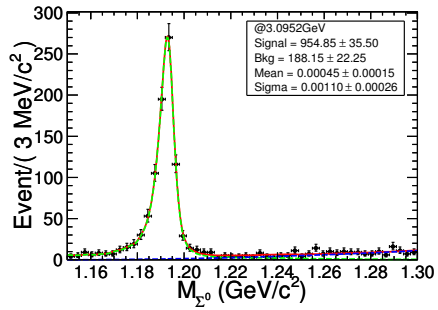


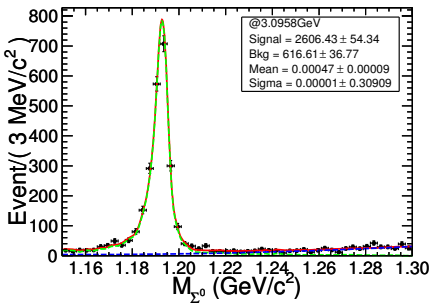


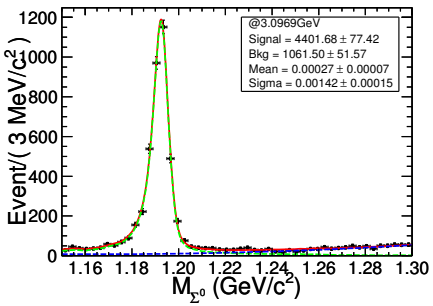


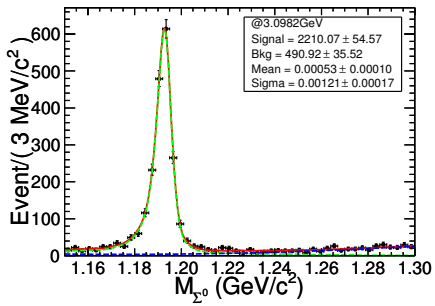


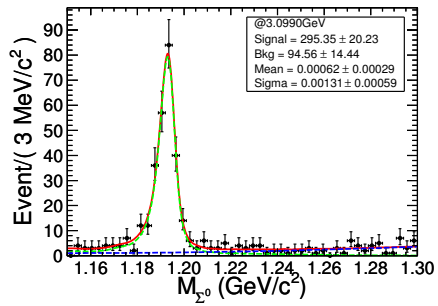


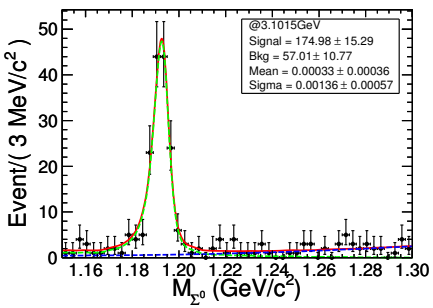


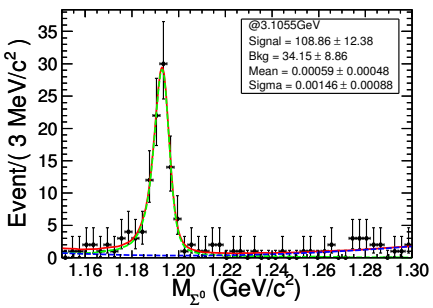


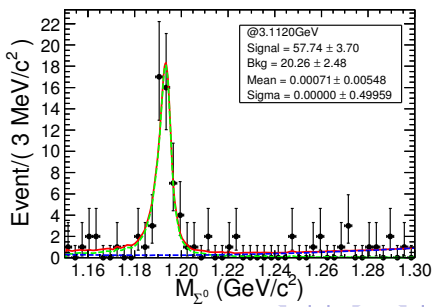


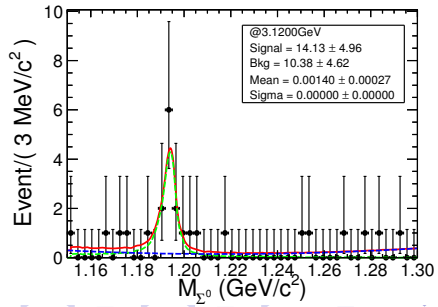




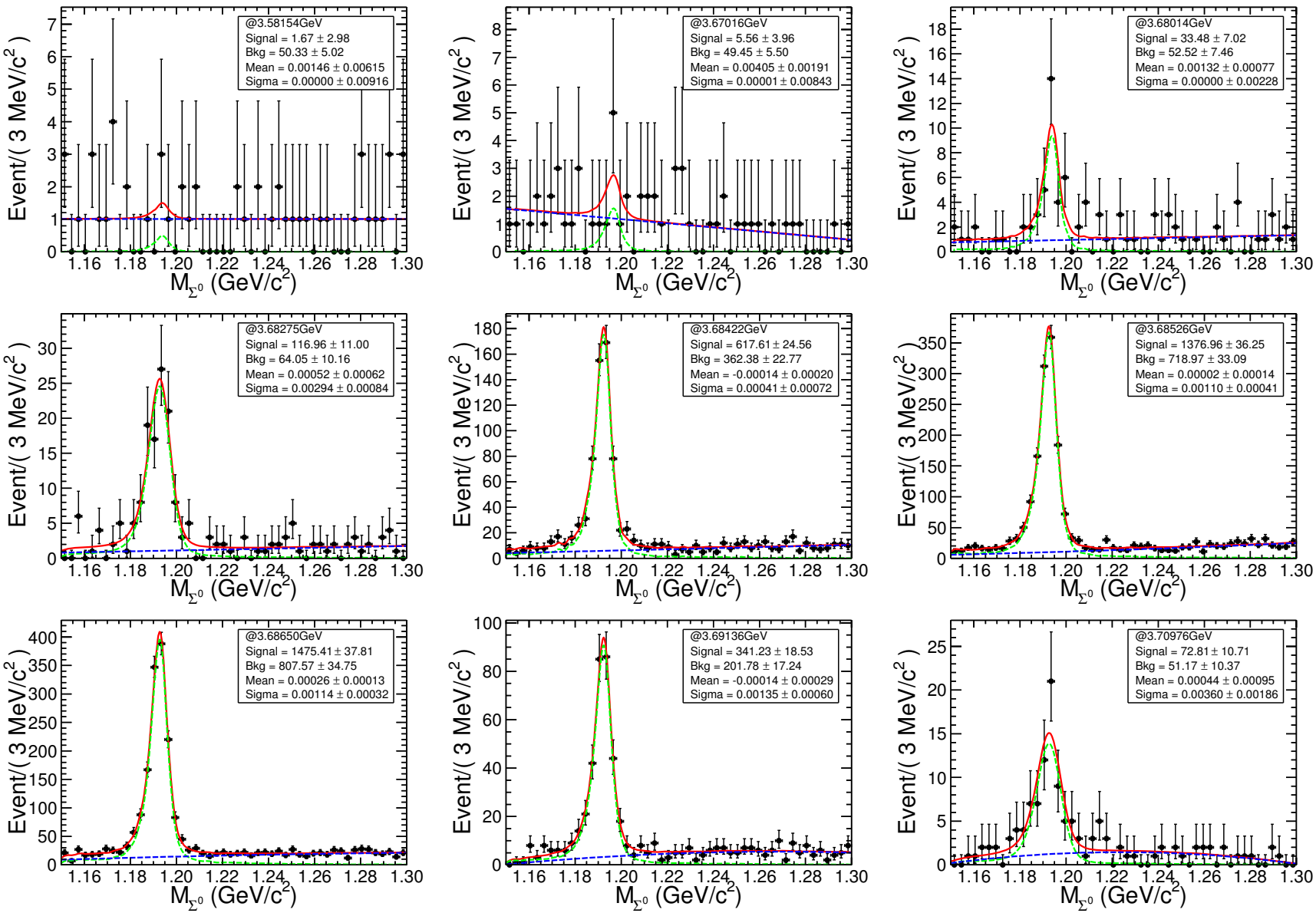








Fitting Results of $\psi(2S)$



Obs input lineshape cross section

CMS (GeV)	I.L (pb-1)	Efficiency	cross (pb)
3.04966	14.919	25.944	3.98859 +/- 1.20325
3.05871	15.06	27.112	3.0298 +/- 1.01453
3.08251	4.769	29.968	4.38602 +/- 2.08433
3.08887	15.558	32.456	9.83688 +/- 1.44996
3.09178	14.91	34.686	13.9256 +/- 1.72481
3.09471	2.143	37.344	253.041 +/- 18.2252
3.09545	1.816	37.6	1094.15 +/- 40.6812
3.09584	2.135	37.628	2538.25 +/- 52.9273
3.09723	2.069	38.024	4378.25 +/- 77.0024
3.09836	2.203	38.318	2048.54 +/- 50.5831
3.09906	0.765	38.184	791.292 +/- 54.1904
3.10137	1.612	37.99	223.601 +/- 19.5363
3.1056	2.106	36.752	110.092 +/- 12.5156
3.11207	1.72	33.95	77.3441 +/- 11.9259
3.11989	1.264	27.562	34.5436 +/- 11.2278