Improved measurements of $\chi_{cJ} \to \Sigma^+\bar{\Sigma}^-$ and $\Sigma^0\bar{\Sigma}^0$ decays

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JC 86 report

Introduction

- Experimental studies of charmonium decays can test calculations in quantum chromodynamics (QCD) and QCD based effective field theories.

- There are large differences between predictions and the experimental measurements, the branching fractions (BF) of $\chi_{c0} \to \Sigma^+\overline{\Sigma}^-$ and $\Sigma^0\overline{\Sigma}^0$ decays as measured by CLEO-c and BESIII are observed to violate the helicity selection rule from perturbative QCD (pQCD) and also do not agree with models based on the charm meson loop mechanism .

- Tests of the color octet mechanism (COM)using more decay channels are an important input for the development of the theoretical models

Event topology

$$1,\psi(3686) \to \gamma\chi_{cJ}, \chi_{cJ} \to \Sigma^{+}\bar{\Sigma}^{-} \begin{matrix} \nearrow \bar{p}\pi^{0} \\ \searrow p\pi^{0} \end{matrix}$$

- **Final states of signal: $5\gamma p\bar{p}$.**

$$2,\psi(3686) \to \gamma\chi_{cJ}, \chi_{cJ} \to \Sigma^{0}\bar{\Sigma}^{0} \begin{matrix} \nearrow \gamma\Lambda \begin{matrix} \nearrow \bar{p}\pi^{+} \\ \searrow p\pi^{-} \end{matrix} \\ \searrow \gamma\bar{\Lambda} \end{matrix}$$

- **Final states of signal: $3\gamma p\bar{p}\pi^{+}\pi^{-}$.**

Event Selection

Channel 1:
select $\pi^0, \Sigma^+, \bar{\Sigma}^-$

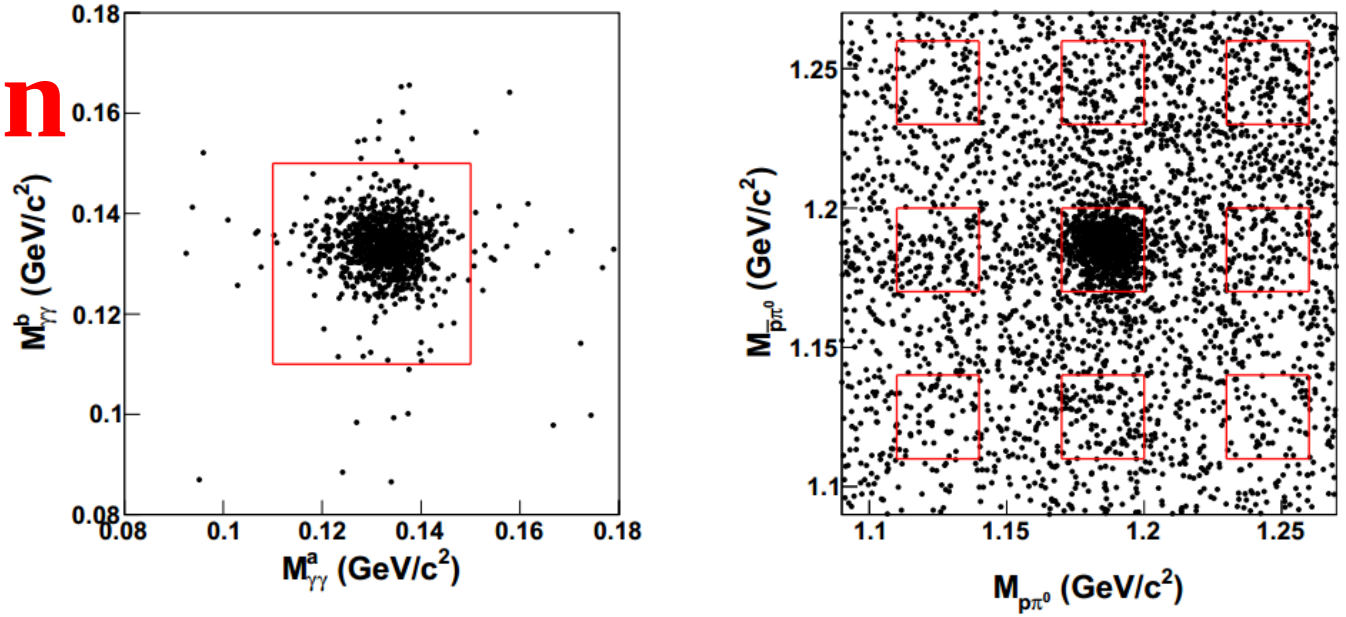


Fig. 1: Distribution of $M^a_{\gamma\gamma}$ versus $M^b_{\gamma\gamma}$ (left) and distribution of $M_{p\pi^0}$ versus $M_{\bar{p}\pi^0}$ (right) for $\chi_{cJ} \to \Sigma^+\bar{\Sigma}^-$. The central (surrounding) boxes indicate the signal (sideband) regions.

Channel 2:
select $\Lambda, \bar{\Lambda}, \Sigma^0, \bar{\Sigma}^0$

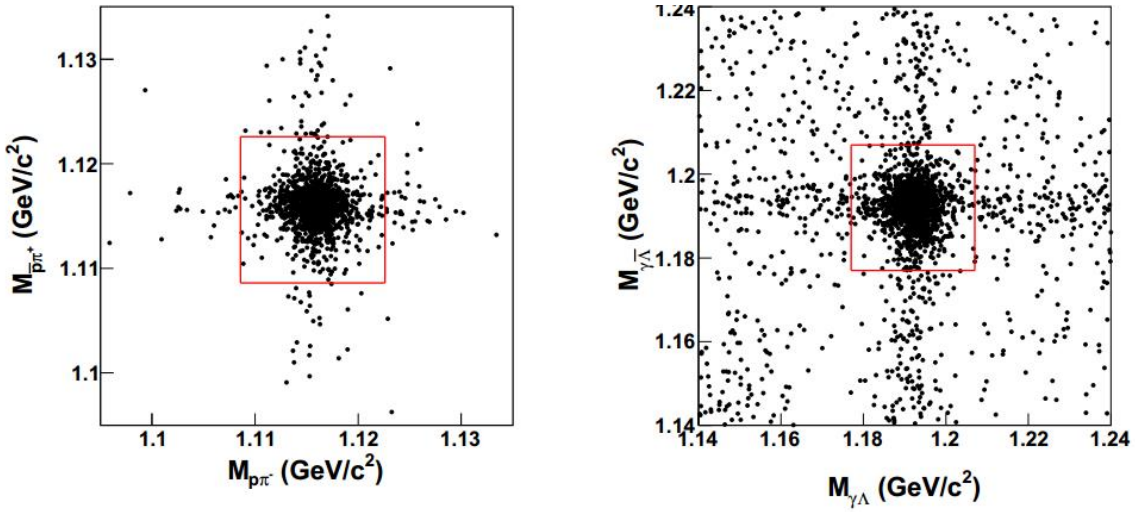


Fig. 3: Distribution of $M_{p\pi^-}$ versus $M_{\bar{p}\pi^+}$ (left) and distribution of $M_{\gamma\Lambda}$ versus $M_{\gamma\bar{\Lambda}}$ (right) for $\chi_{cJ} \to \Sigma^0\bar{\Sigma}^0$. The solid boxes indicate the signal regions.

Determination of the χ_{cJ} signals

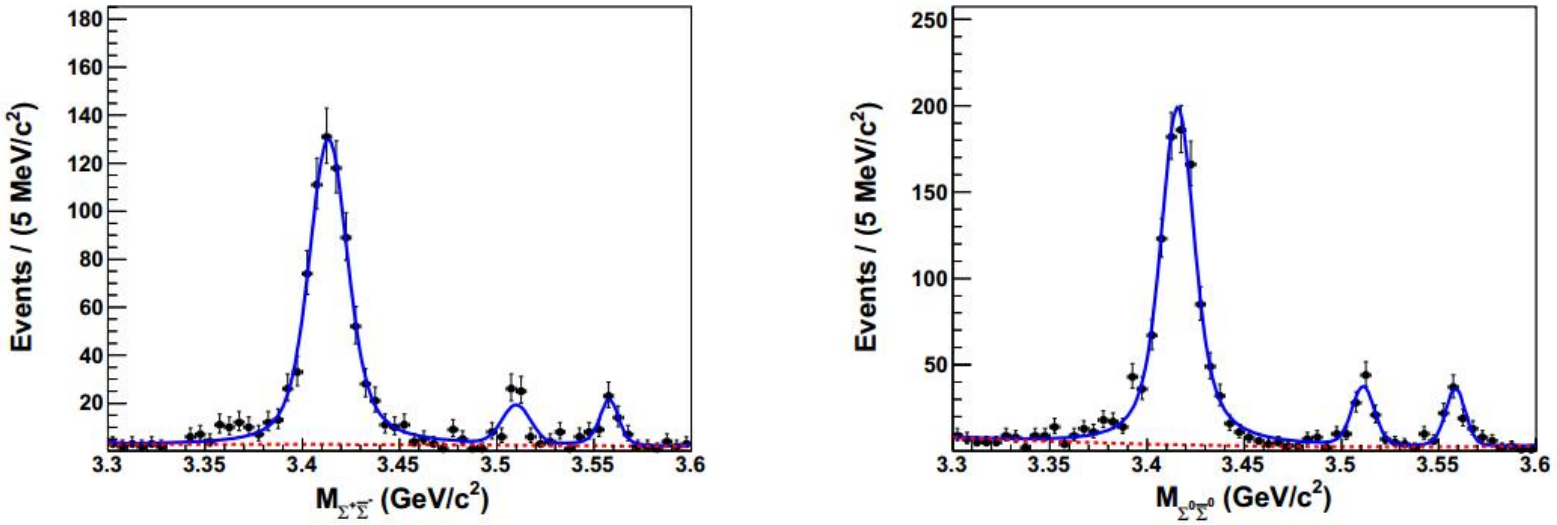


Fig. 4: Fit results to the invariant mass spectra of $\Sigma^+\bar{\Sigma}^-$ (left) and $\Sigma^0\bar{\Sigma}^0$ (right). The dots with error bars represent the data, the solid line represents the fit results and the dashed line represents the smooth background.

$$F_J(m) = (BW_J(m) \times E_\gamma^3 \times D(E_\gamma)) \otimes G(0; \sigma_{\mathrm{res},J}),$$

where $BW_J(m)$ is a Breit-Wigner function; $G(0; \sigma_{\mathrm{res},J})$ is a Gaussian function with the mean value of zero and a standard deviation of the detection resolution $\sigma_{\mathrm{res},J}$; E_γ^3 is the cube of radiative photon energy reflecting the energy dependence of the electric dipole (E1) matrix element; $D(E_\gamma)$ is a damping factor needed to suppress the diverging tail caused by the E_γ^3 dependence and is given by $e^{-\frac{E_\gamma^2}{8\beta^2}}$, with $\beta = 65$ MeV as determined by the CLEO collaboration [20]. The background is described by a second-order Chebychev polynomial function. In

Result

TABLE II: The BF results for the measurement of $\chi_{cJ} \to \Sigma^+\bar{\Sigma}^-$ and $\Sigma^0\bar{\Sigma}^0$ (second column), together with values from PDG world average [17], previous measurement from BESIII publications [6], CLEO [5] and theoretical predictions [2–4] for comparison. To make an objective comparison, the BF of $\chi_{cJ} \to \Sigma\bar{\Sigma}$ decays from previous BESIII are corrected with the newest BF of $\psi(3686) \to \gamma\chi_{cJ}$ from Ref. [17]. To be independent of the BF of $\psi(3686) \to \gamma\chi_{cJ}$, the product BF ($\mathcal{B}_{\rm prod}$) of $\psi(3686) \to \gamma\chi_{cJ}$ and $\chi_{cJ} \to \Sigma\bar{\Sigma}$ are also listed (last column). The first uncertainty is statistical and the second systematic. Throughout the table, the BFs are given in units of 10^{-5}.

Channel	This work	PDG	Previous BESIII [6]	CLEO [5]	Theory	$\mathcal{B}_{\rm prod}$
$\chi_{c0} \to \Sigma^+\bar{\Sigma}^-$	$50.4 \pm 2.5 \pm 2.7$	39 ± 7	$43.7 \pm 4.0 \pm 2.8$	$32.5 \pm 5.7 \pm 4.3$	5.5-6.9 [3]	$4.99 \pm 0.24 \pm 0.24$
$\chi_{c1} \to \Sigma^+\bar{\Sigma}^-$	$3.7 \pm 0.6 \pm 0.2$	< 6	$5.2 \pm 1.3 \pm 0.5 (< 8.3)$	< 6.5	3.3 [4]	$0.35 \pm 0.06 \pm 0.02$
$\chi_{c2} \to \Sigma^+\bar{\Sigma}^-$	$3.5 \pm 0.7 \pm 0.3$	< 7	$4.7 \pm 1.8 \pm 0.7 (< 8.4)$	< 6.7	5.0 [4]	$0.32 \pm 0.06 \pm 0.03$
$\chi_{c0} \to \Sigma^0\bar{\Sigma}^0$	$47.7 \pm 1.8 \pm 3.5$	44 ± 4	$46.0 \pm 3.3 \pm 3.7$	$44.1 \pm 5.6 \pm 4.7$	$(25.1 \pm 3.4,\ 18.7 \pm 4.5)$ [2]	$4.72 \pm 0.18 \pm 0.28$
$\chi_{c1} \to \Sigma^0\bar{\Sigma}^0$	$4.3 \pm 0.5 \pm 0.3$	< 4	$3.7 \pm 1.0 \pm 0.5 (< 6.0)$	< 4.4	3.3 [4]	$0.41 \pm 0.05 \pm 0.03$
$\chi_{c2} \to \Sigma^0\bar{\Sigma}^0$	$3.9 \pm 0.5 \pm 0.3$	< 6	$3.8 \pm 1.0 \pm 0.5 (< 6.2)$	< 7.5	$(38.9 \pm 8.8,\ 4.2 \pm 0.5)$ [2] 5.0 [4]	$0.35 \pm 0.05 \pm 0.02$

$\Sigma^0\bar{\Sigma}^0$. The results presented replace the previous BESIII results [6]. The decays $\chi_{c1,2} \to \Sigma^+\bar{\Sigma}^-$ and $\Sigma^0\bar{\Sigma}^0$ are observed with more than 5σ significance for the first time. The results are consistent with and improve on the precision compared to the world average values. The current results on $\chi_{c1,2} \to \Sigma^+\bar{\Sigma}^-$ and $\Sigma^0\bar{\Sigma}^0$ are in good agreement with theoretical predictions based on the color octet contribution model [4]. The results for $\chi_{c0} \to \Sigma^+\bar{\Sigma}^-$ and $\Sigma^0\bar{\Sigma}^0$ are still inconsistent with the prediction [3] based on the charm meson loop mechanism. The ratio between charged and neutral decay modes is consistent with the expectation from isospin symmetry.

Question from Xin

Could you briefly explain what is the “color octet mechanism (OCM)” ? Probably with Feynman diagram …

Answer: It’s a model in the Non-relativistic Quantum Chromodynamics, (NRQCD), it is used to deal with the decay of the colored heavy quark-antiquark pairs on the short and long distance scale problem.

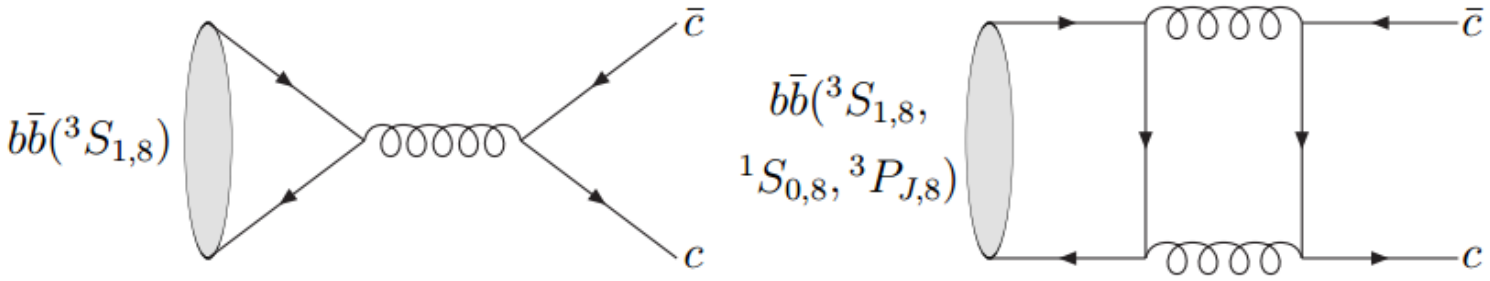


图 5.2　色八重态的 $b\bar{b} \to c\bar{c}$ 的费曼图

- **Question from AMIT**
- Can you please explain what is Helicity Selection Rule with a suitable example?
- Answer:

We briefly review this powerful method that is elaborated on in Ref. [2]. For a charmonium meson $J_{c\bar{c}}$ decaying into two light mesons h_1 and h_2, the perturbative method gives the asymptotic behavior of the branching ratio as follows

$$BR_{J_{c\bar{c}}(\lambda)\to h_1(\lambda_1)h_2(\lambda_2)} \sim \left(\frac{\Lambda^2_{QCD}}{m_c^2}\right)^{|\lambda_1+\lambda_2|+2}, \tag{1}$$

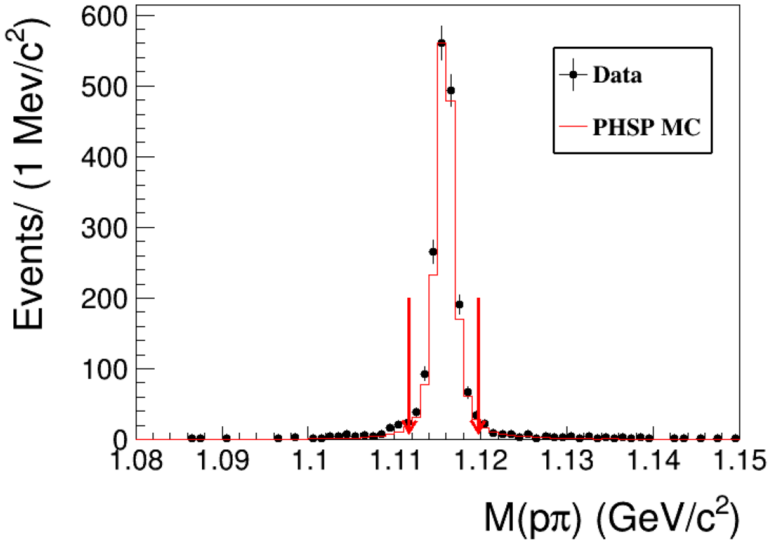
where λ, λ_1, and λ_2 are the helicities of the corresponding mesons. This is the result of the pQCD method to leading-twist accuracy; i.e. only the valence Fock state (here it is $c\bar{c}$) is considered. It is obvious that the leading contribution comes from when $\lambda_1 + \lambda_2 = 0$, (while the higher twist will be suppressed by at least a factor of Λ^2_{QCD}/m_c^2.) while the helicity configurations which do not satisfy this relation will be suppressed.

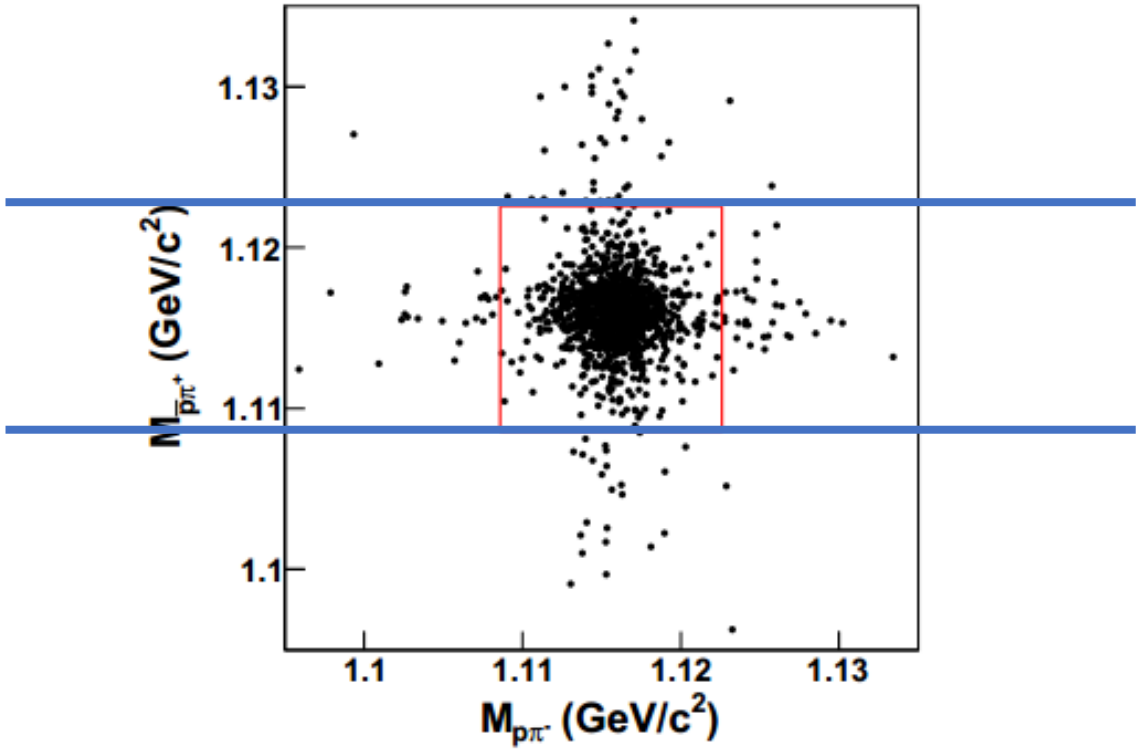
Question from Yuzhen

- In Fig.3 (left), the density of black point in the center is highest, but density of up, underneath, left and right side of the center is a little higher than other places, why?

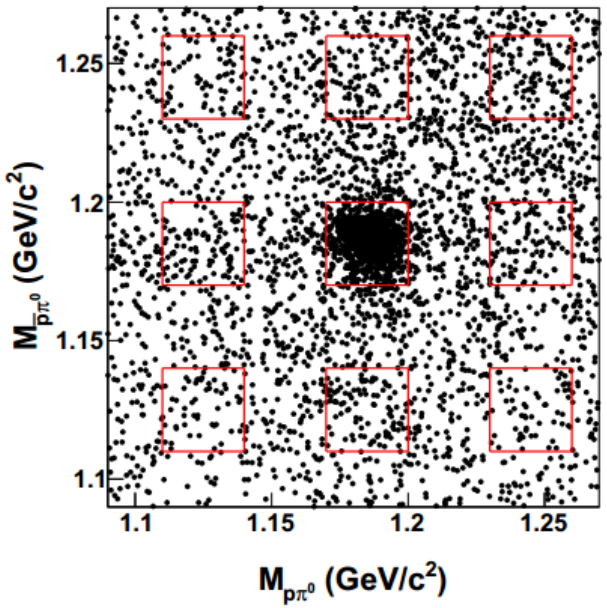
Answer:1, He has selected the clean Λ signals.

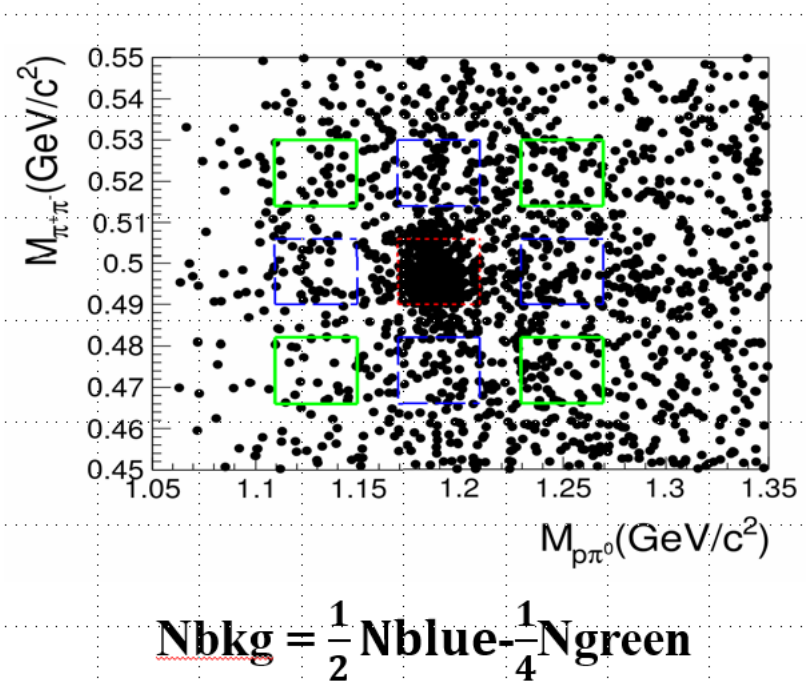
2,The width of Λ is very narrow.



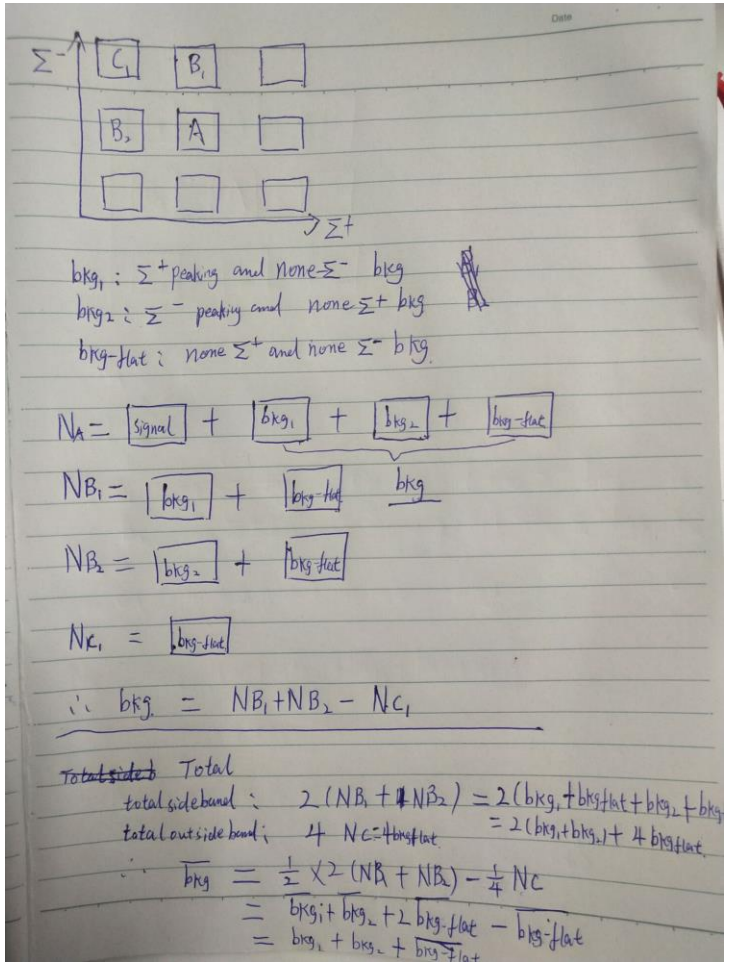


- **Question from Suyu**
- In right panel of figure 1, what's the rule to select such the boxes as background? As I remember, you did some similar thing in your analysis. Why some box contributes as 1/2 while others 1/2?



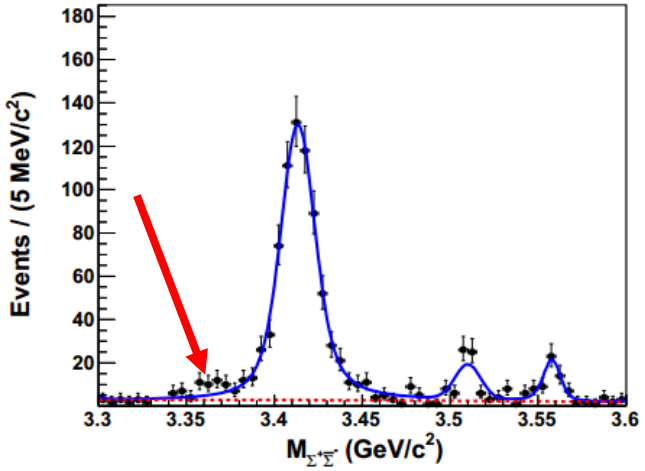


$$\mathbf{Nbkg} = \frac{1}{2}\mathbf{Nblue} - \frac{1}{4}\mathbf{Ngreen}$$



- **Question from Kai**
- section V, the PDF of signal peaks including a Gaussian function, why the mean value is set to be zero?
- **Answer:** Actually, if we didn't set it to be zero, the mean of the shape will shift because of the convolution. Usually we will set it to 0. otherwise it will give a very small change interval.

- **Question from Ryuta**
- In the Fig.4 (left), the invariant mass of Sigma+/Sigma-, I could find a small bump-like structure around 3.36-3.37 GeV. If I check that for the case of Sigma+/Pbar/K0short, as you have shown last week, there also would be a similar structure on this region.
- Is there any internal discussion on this structure (possibly some background ?) or not ?
- Answer: No discussion on this.



- **Question from Yuhang**
- In TABLE II,the theoretical value is far from the measured value in χc0 ->Σ+Σ- channel. In summary , it also say: "The results for χc0 ->Σ+Σ- and χc0 ->Σ0Σ0 are still inconsistent with the prediction." What caused this result?
- Answer: $\chi_{c0} \to \Sigma\bar{\Sigma}$ is supposed to be highly suppressed by the helicity selection rule. However, J. Phys. G 38, 035007 (2011) results indicate that the transitions via these kinds of loops as long-distance effects can give significant contributions. This is a further test of the mechanism for the evasion of helicity selection rule that proposed in Phys. Rev. D 81, 014017 (2010) .

Here, the result from experiment is more bigger than f the result from the J. Phys. G 38, 035007 (2011) prediction. So may be theorists can propose more models or explanations.(I don't know……)

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