Misure di polarizzazione e BR dei decadimenti dei mesoni J/ψ e $\psi(2S)$ in $\Sigma^+\overline{\Sigma}^-$

ALESSIO MANGONI

ON BEHALF OF THE BESIII COLLABORATION

Istituto Nazionale di Fisica Nucleare - sezione di Perugia
Università degli Studi di Perugia - Dipartimento di Fisica e Geologia
BESIII collaboration

Agenda

- The BESIII experiment
- The process $e^+e^- \to \psi \to \Sigma^+\overline{\Sigma}^-$
- Polarization in $\Sigma^+\overline{\Sigma}^-$ production
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- Branching ratios
- Strong-EM relative phase
- Conclusion

Phys.Rev.Lett. 125 (2020) 5, 052004

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Σ^+ and $\bar{\Sigma}^-$ Polarization in the J/ψ and $\psi(3686)$ Decays

M. Ablikim *et al.* (BESIII Collaboration)
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Strong and electromagnetic amplitudes of the J/ψ decays into baryons and their relative phase

Rinaldo Baldini Ferroli [a], Alessio Mangoni [b,c,*], Simone Pacetti [b,c], Kai Zhu [d]

[a] *INFN Laboratori Nazionali di Frascati, I-00044, Frascati, Italy*
[b] *Università di Perugia, I-06100, Perugia, Italy*
[c] *INFN Sezione di Perugia, I-06100, Perugia, Italy*
[d] *Institute of High Energy Physics, I-100049, Beijing People's Republic of China*

The BESIII experiment

Beijing Electron-Positron Collider (started in 1984, first operation in 1989, upgrade to BEPCII in 2008)
BEPCII is a double ring machine (peak luminosity: $1.0 \times 10^{33}\ \mathrm{cm}^{-2}\,\mathrm{s}^{-1}$ - CM energy $2.0 \div 4.6\,(4.7)\ \mathrm{GeV}$)

***Chin.Phys.C* 44 (2020) 4, 040001**

Nature Rev.Phys. 1 (2019) no.8, 480-494

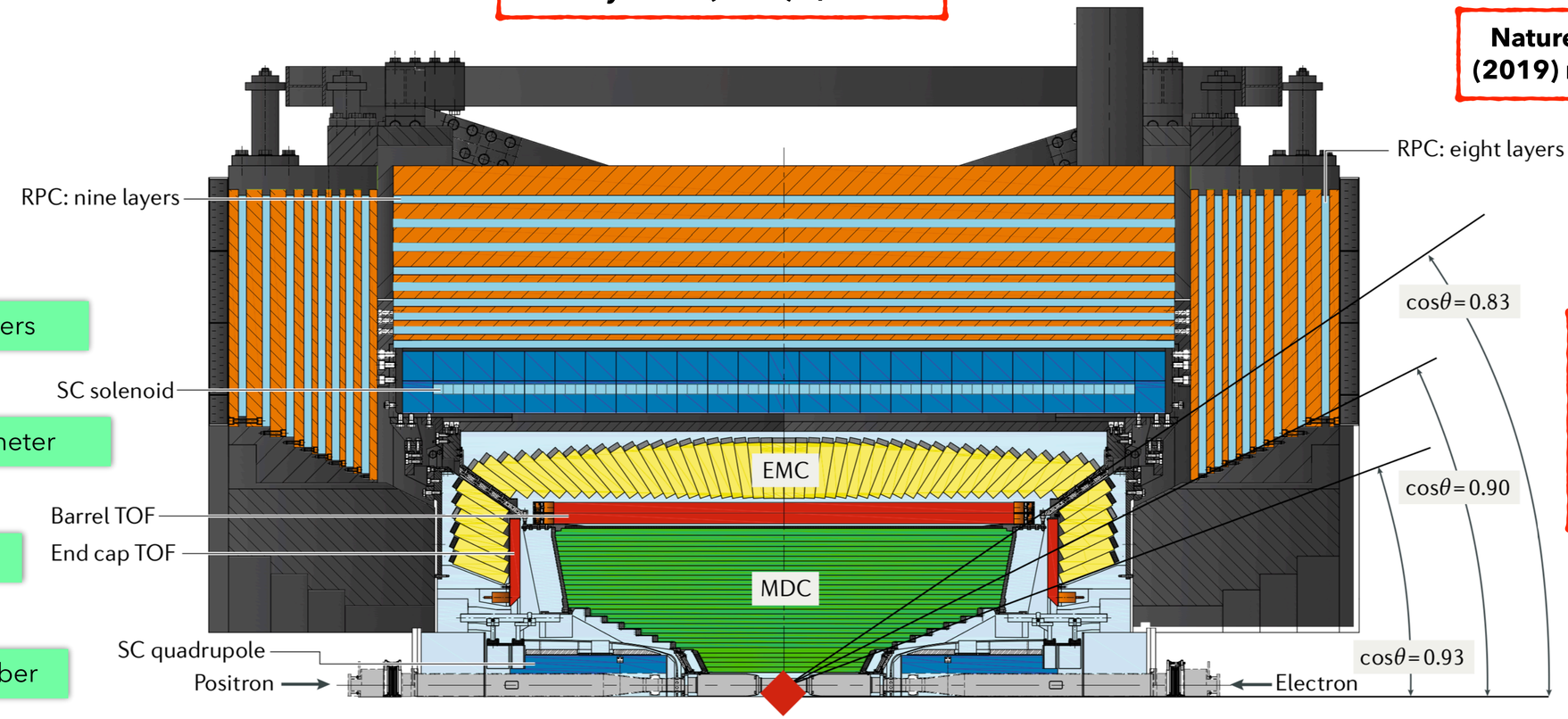
Solid angle: 93% of 4π covered

Resistive Plate Chambers

Electromagnetic calorimeter

Time-Of-Flight

Multi-layer Drift Chamber



See also the talk "L'esperimento BESIII: Risultati e prospettive per il futuro" by I. Garzia

The process $e^+e^- \to \psi \to \Sigma^+\overline{\Sigma}^-$

- Hyperons are ideal probes for studying the strong interaction in the transition region where the regime is not completely perturbative; **Phys.Rev.Lett. 125 (2020) 5, 052004**
- The polarization of Λ baryons in the process $e^+e^- \to J/\psi \to \Lambda\overline{\Lambda}$ was recently measured by BESIII; ***Nature Phys.* 15 (2019) 631-634**
- We consider the process $e^+e^- \to \psi \to \Sigma^+(p\pi^0)\overline{\Sigma}^-(\bar{p}\pi^0)$ $\psi \in \{J/\psi, \psi(2S)\}$
- The polarization of Σ hyperons can be determined analyzing the two-body weak decays $\Sigma^+ \to p\pi^0$ and $\overline{\Sigma}^- \to \bar{p}\pi^0$
- The $e^+e^- \to \psi \to \Sigma^+\overline{\Sigma}^-$ production process is described by the psionic electric and magnetic form factors (FFs) G_E^{ψ} and $G_{M'}^{\psi}$ related to the parameters α_ψ and $\Delta\Phi$

α_ψ is the angular decay asymmetry parameter

$\Delta\Phi$ is the relative phase between FFs

Polarization in $\Sigma^+\overline{\Sigma}^-$ production

Study of entangled Σ^+ and $\overline{\Sigma}^-$ produced in the process $e^+e^- \to \psi \to \Sigma^+\overline{\Sigma}^-$

$\psi \in \{J/\psi, \psi(2S)\}$

The observable $\Delta\Phi$ is related to the spin-polarization of the produced $\Sigma^+\overline{\Sigma}^-$ pair

If $\Delta\Phi \neq 0$ the Σ polarization is perpendicular to the scattering plane and depends on θ_{Σ^+}

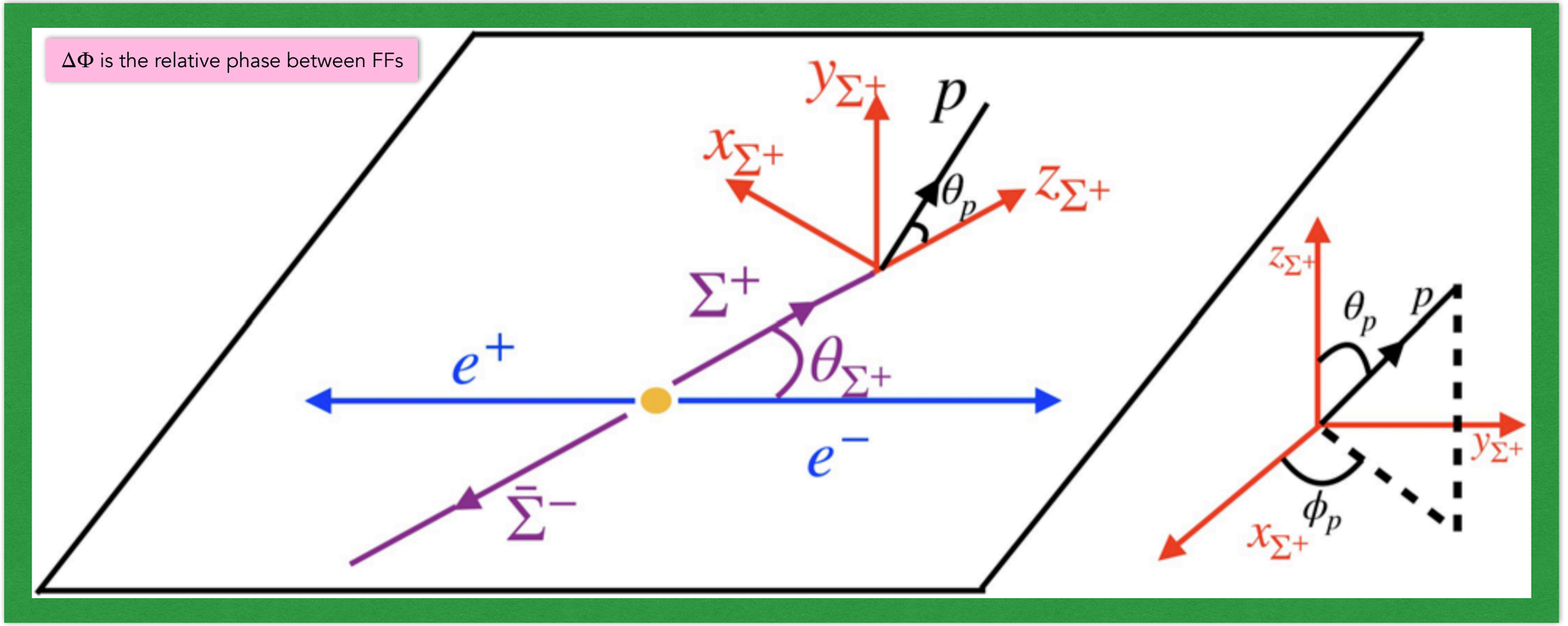


Illustration of the $e^+e^- \to \psi \to \Sigma^+\overline{\Sigma}^-$ process

Polarization in $\Sigma^+\overline{\Sigma}^-$ production

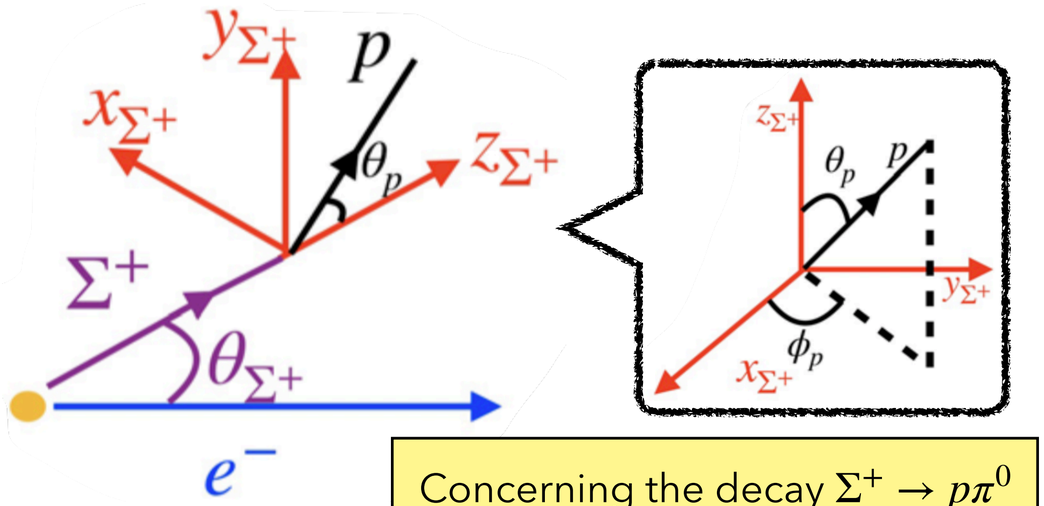
The analysis is based on 1.3106×10^9 J/ψ and 448.1×10^6 $\psi(2S)$ events collected with the BESIII detector

The full differential cross section of the production and decay process $e^+e^- \to \psi \to \Sigma^+(p\pi^0)\overline{\Sigma}^-(\bar{p}\pi^0)$ is described with five observables $\xi = (\theta_{\Sigma^+}, \theta_p, \phi_p, \theta_{\bar{p}}, \phi_{\bar{p}})$

$$\mathcal{W}(\boldsymbol{\xi}) = \mathcal{T}_0(\boldsymbol{\xi}) + \alpha_\psi \mathcal{T}_5(\boldsymbol{\xi}) + \alpha_0\bar{\alpha}_0[\mathcal{T}_1(\boldsymbol{\xi}) + \sqrt{1-\alpha_\psi^2}\cos(\Delta\Phi)\mathcal{T}_2(\boldsymbol{\xi}) + \alpha_\psi \mathcal{T}_6(\boldsymbol{\xi})] + \sqrt{1-\alpha_\psi^2}\sin(\Delta\Phi)[\alpha_0\mathcal{T}_3(\boldsymbol{\xi}) + \bar{\alpha}_0\mathcal{T}_4(\boldsymbol{\xi})].$$

$$d\sigma \propto \mathcal{W}(\boldsymbol{\xi})d\boldsymbol{\xi}$$

$\mathcal{T}_i, (i = 0, 1, \ldots, 6)$ are angular functions dependent on ξ *[Phys.Lett.B 772 (2017) 16-20]*



z axis along the Σ^+ momentum

Concerning the decay $\Sigma^+ \to p\pi^0$

$$\frac{dN}{d\Omega} = \frac{1}{4\pi}(1 + \alpha_0 \boldsymbol{P}_{\Sigma^+} \cdot \hat{\boldsymbol{p}})$$

$\hat{\boldsymbol{p}}$ is the unit vector along p momentum in the Σ^+ rest frame

α_0 is the asymmetry parameter

$\boldsymbol{P}_{\Sigma^+}$ is the Σ^+ polarization vector

(similarly for $\overline{\Sigma}^- \to \bar{p}\pi^0$, with $\bar{\alpha}_0$)

Fit of the joint angular distribution $\mathcal{W}(\boldsymbol{\xi})$ → determination of α_ψ , $\Delta\Phi$, α_0 , $\bar{\alpha}_0$

BESIII results

The FFs relative phases are determined to be

$$\Delta\Phi_{J/\psi} = (-15.5 \pm 0.7\,(\text{stat}) \pm 0.5\,(\text{syst}))^\circ$$
$$\Delta\Phi_{\psi(2S)} = (21.7 \pm 4.0\,(\text{stat}) \pm 0.8\,(\text{syst}))^\circ$$

The obtained decay asymmetry parameters are

$$\alpha_0 = -0.998 \pm 0.037\,(\text{stat}) \pm 0.009\,(\text{syst})$$
$$\bar{\alpha}_0 = 0.990 \pm 0.037\,(\text{stat}) \pm 0.011\,(\text{syst})$$

where $\bar{\alpha}_0$ has been measured for the first time

Test of CP violation

$$A_{\text{CP},\Sigma} = \frac{\alpha_0 + \bar{\alpha}_0}{\alpha_0 - \bar{\alpha}_0} = -0.004 \pm 0.037 \pm 0.010$$

$$A_{\text{CP},\Sigma}^{\text{Standard Model}} \sim 3.6 \times 10^{-6}$$

***Phys.Rev.D* 67 (2003) 056001**

Phys.Rev.Lett. 125 (2020) 5, 052004

Parameter	Measured value
$\alpha_{J/\psi}$	$-0.508 \pm 0.006 \pm 0.004$
$\Delta\Phi_{J/\psi}$	$-0.270 \pm 0.012 \pm 0.009$
$\alpha_{\psi'}$	$0.682 \pm 0.03 \pm 0.011$
$\Delta\Phi_{\psi'}$	$0.379 \pm 0.07 \pm 0.014$
α_0	$-0.998 \pm 0.037 \pm 0.009$
$\bar{\alpha}_0$	$0.990 \pm 0.037 \pm 0.011$

BESIII has collected $\sim 10^{10}$ J/ψ events and it is expected to collect $\sim 3 \times 10^9$ $\psi(2S)$ that can be used to reduce the statistical errors

Branching ratios

- Two-body baryonic decays of charmonium provide a good laboratory for studying the properties of baryons
- Preliminary results are available from BESIII for the measurement of the BRs for the $\psi \to \Sigma^+\overline{\Sigma}^-$ decay

Discrepancy from the PDG value of about 1.9 sigma

$\psi \in \{J/\psi, \psi(2S)\}$

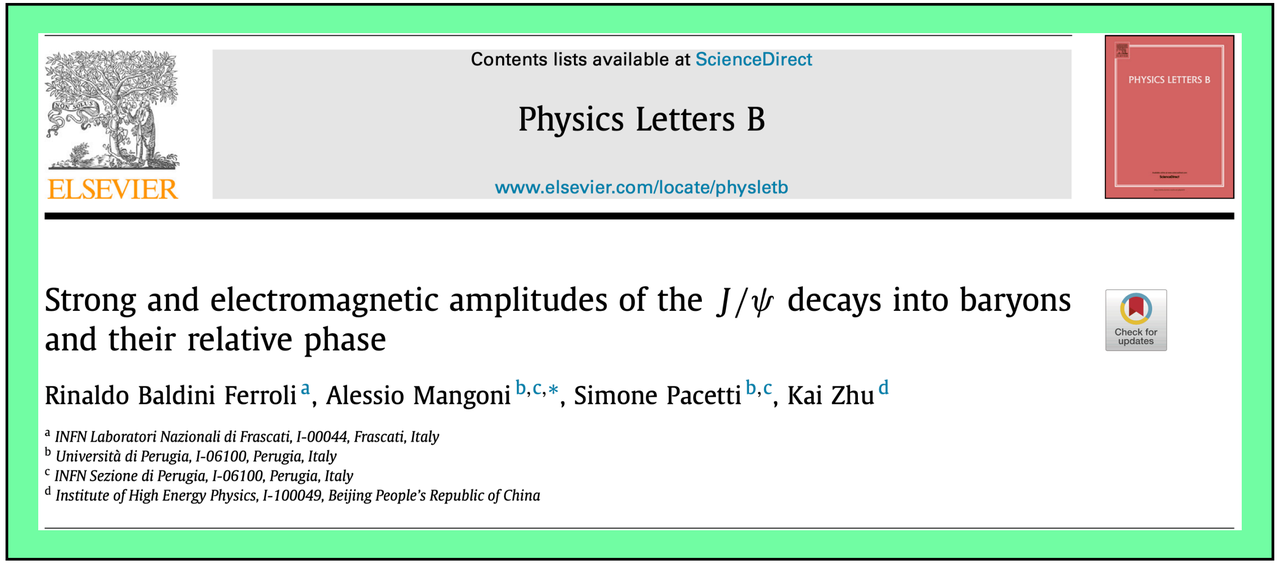
Decay	Branching ratio	Branching ratio from PDG
$J/\psi \to \Sigma^+\overline{\Sigma}^-$	$(1.044 \pm 0.004\,(\text{stat})) \times 10^{-3}$	$(1.50 \pm 0.24) \times 10^{-3}$
$\psi(2S) \to \Sigma^+\overline{\Sigma}^-$	$(2.46 \pm 0.03\,(\text{stat})) \times 10^{-4}$	$(2.32 \pm 0.12) \times 10^{-3}$

The total systematic uncertainty are less than 5%

Prog.Theor.Exp.Phys. (2020) 083C01

Branching ratios

These results are <u>fully in agreement</u> with our recently theoretical predictions based on a strong Lagrangian with SU(3) symmetry breaking terms



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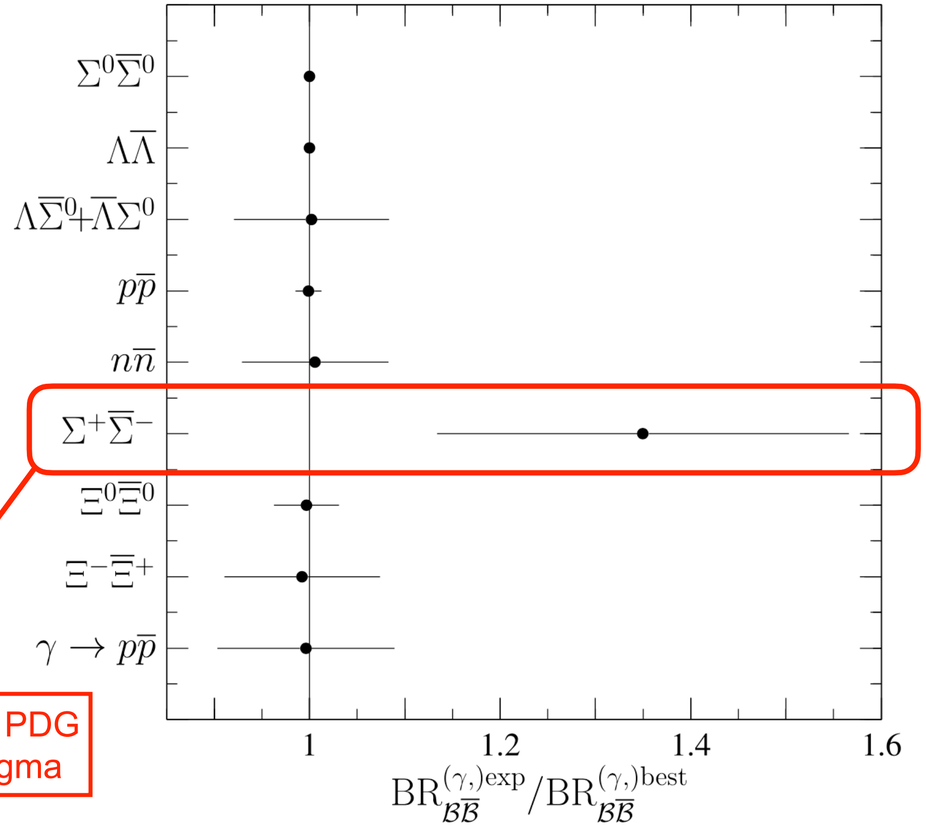
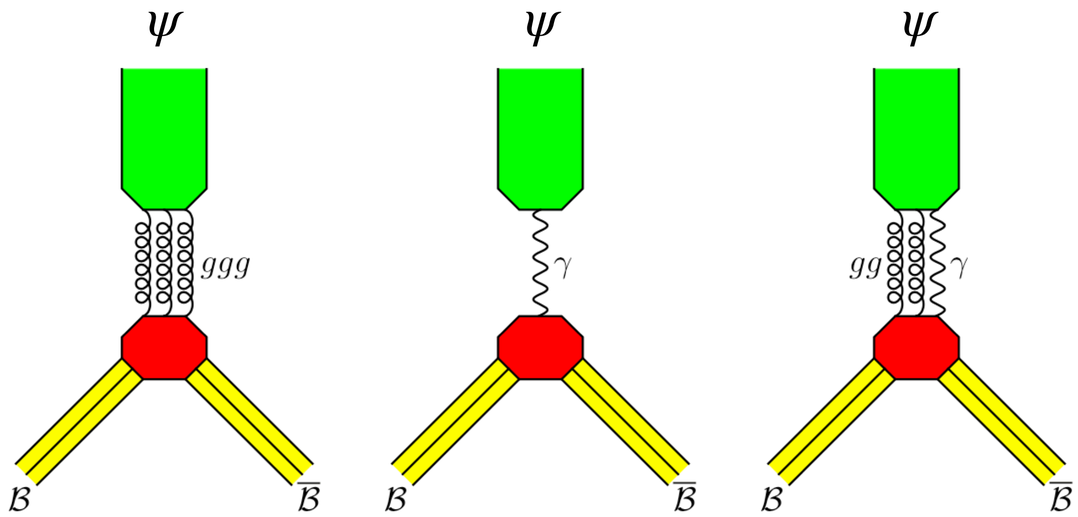


Our prediction: $\mathrm{BR}_{J/\psi\to\Sigma^+\overline{\Sigma}^-} = (1.110 \pm 0.086) \times 10^{-3}$

Discrepancy from the PDG value of about 1.5 sigma

Strong-EM relative phase

Amplitude parametrization for $\psi \to$ baryon-antibaryon decay



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$$\mathscr{A}_{J/\psi} = \mathscr{A}_{ggg} + \mathscr{A}_{gg\gamma} + \mathscr{A}_{\gamma}$$

$$R \equiv \frac{\mathscr{A}_{gg\gamma}}{\mathscr{A}_{ggg}}$$

$$B = \begin{pmatrix} \frac{\Lambda}{\sqrt{6}} + \frac{\Sigma^0}{\sqrt{2}} & \Sigma^+ & p \\ \Sigma^- & \frac{\Lambda}{\sqrt{6}} - \frac{\Sigma^0}{\sqrt{2}} & n \\ \Xi^- & \Xi^0 & -\frac{2\Lambda}{\sqrt{6}} \end{pmatrix}$$

$$\mathscr{A}_{J/\psi} = \mathscr{A}_{ggg}(1+R) + \mathscr{A}_{\gamma}$$

$$|R_{\mathrm{pQCD}}| \sim \frac{4}{5}\frac{\alpha}{\alpha_S} \quad \& \quad R_{\mathrm{pQCD}} \in \mathbb{R}$$

Strong-EM relative phase

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J/ψ

- The regime of QCD is not completely perturbative
- The obtained strong-EM relative phase is $\varphi = 73^\circ \pm 8^\circ$
- The strong, EM and mixed strong-EM amplitudes have been separated for the first time

arXiv 2005.11265 [hep-ph]

$\psi(2S)$

- For the $\psi(2S)$ meson the work is still in progress
- The strong-EM relative phase is compatible with the hypothesis of orthogonality
- The isospin violating contributions seem to be not negligible

arXiv 2007.12380 [hep-ph]

Conclusion

- Study of the polarization in $e^+e^- \to \psi \to \Sigma^+\bar{\Sigma}^-$ processes by BESIII $\quad \psi \in \{J/\psi, \psi(2S)\}$

- Determination of the polarization parameters α_0 , $\bar{\alpha}_0$ and the FFs relative phase $\Delta\Phi$
- The parameter $\bar{\alpha}_0 = 0.990 \pm 0.037\,(\text{stat}) \pm 0.011\,(\text{syst})$ has been measured for the first time

- The BR for the $J/\psi \to \Sigma^+\bar{\Sigma}^-$ decay has been recently determined by two independent analysis obtaining in both cases a value at least 1.5 sigmas lower than that of PDG

- The obtained relative phase between strong and EM amplitudes for the J/ψ decays into spin-1/2 baryon pairs is $\varphi = 73^\circ \pm 8^\circ$, while in the case of the $\psi(2S)$ meson the work is still in progress and the relative phase is compatible with the hypothesis of orthogonality