

Test of isospin violation in the decay of charmonium into $\Lambda\bar{\Sigma}^0 + c.c.$

BESIII Italia - Torino 2025

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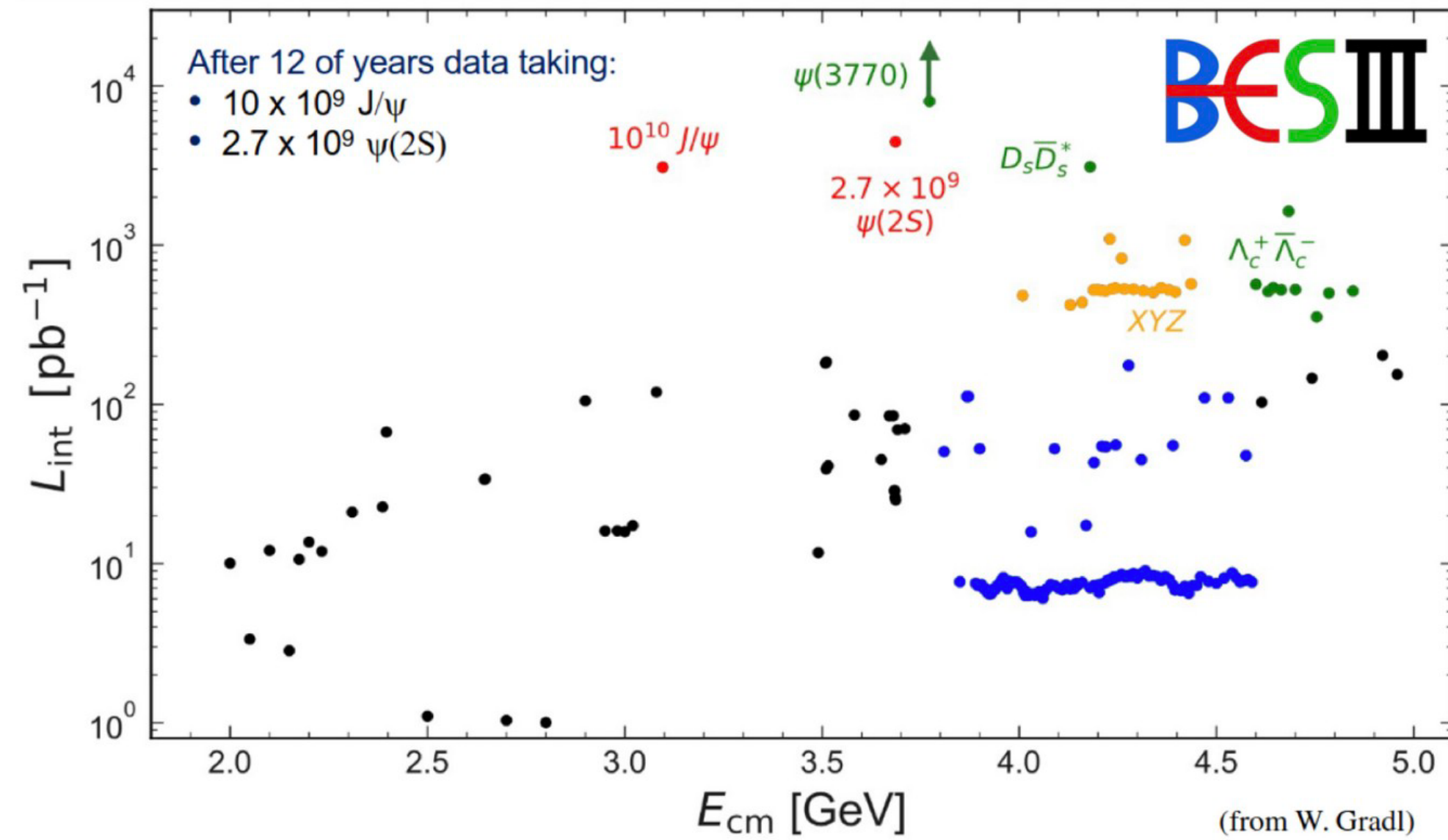
Istituto Nazionale di Fisica Nucleare
Sezione di Perugia



Overview

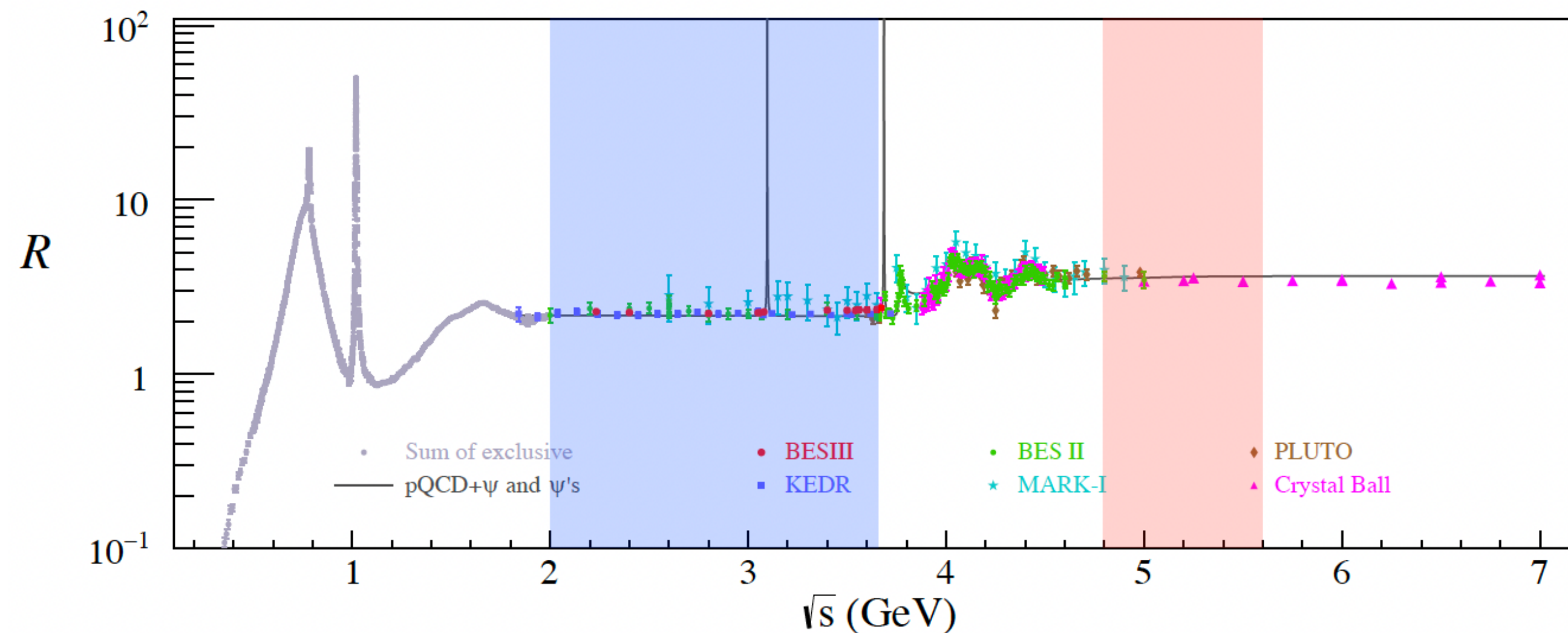
- Introduction to form factors and ψ decays
- Normalized cross section and parameter extraction
- Isospin-violating contributes
- Results and discussion

BESIII datasets



- C.O.M. energy in range 2-5 GeV;
- Luminosity: $1.1 \times 10^{33} \text{ cm}^{-2}\text{s}^{-1}$ @ 3.77 GeV.

Largest e^+e^- datasets at τ -charm energies



- $10^{10} J/\psi$ and $2.7 \times 10^9 \psi(2S)$ produced;
- 20 fb^{-1} @ 3.77 GeV;
- More than 40 fb^{-1} between 3.77 and 5 GeV;
- More than 170 scanning points.

Electromagnetic Form Factors

$$\Gamma_{\text{had}}^{\mu}(p_1, p_2) = \gamma^{\mu} F_1^B(q^2) + \frac{i\sigma^{\mu\nu} q_{\nu}}{2M_B} F_2^B(q^2)$$

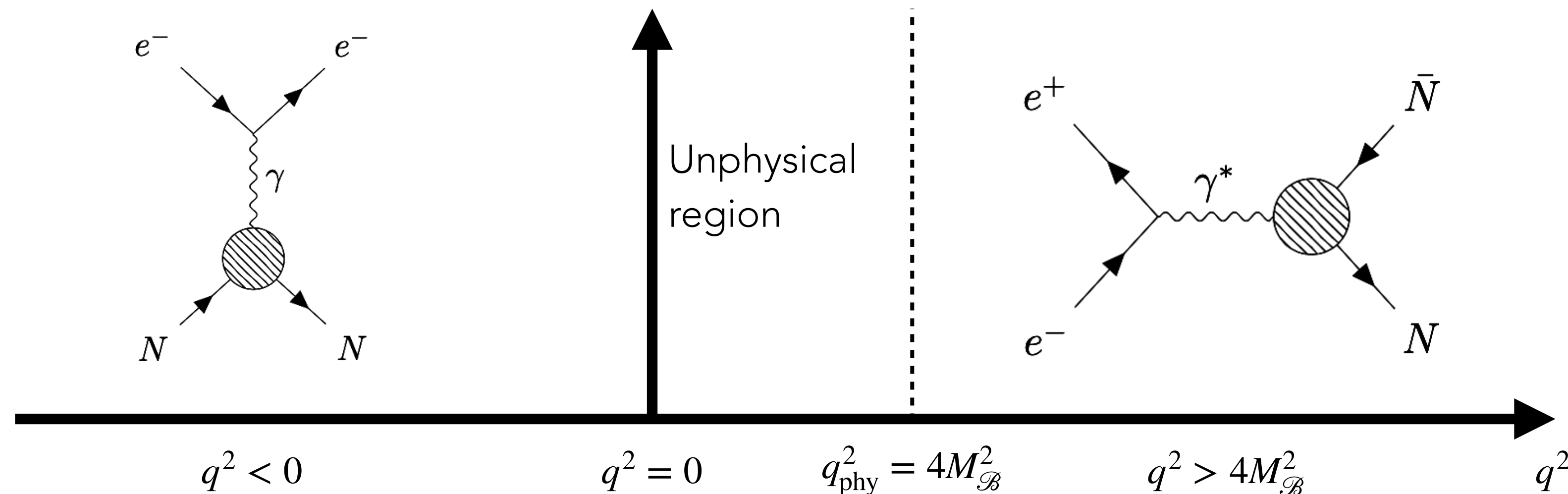
Cross section

$$\sigma_{BB}(q^2) = \frac{4\pi\alpha^2\beta_{M_B}(q^2)}{3q^2} \overbrace{\left(\frac{2M_B^2}{q^2} |G_E^B(q^2)|^2 + |G_M^B(q^2)|^2 \right)}^{|A_{B\bar{B}}^{\gamma}|^2}$$

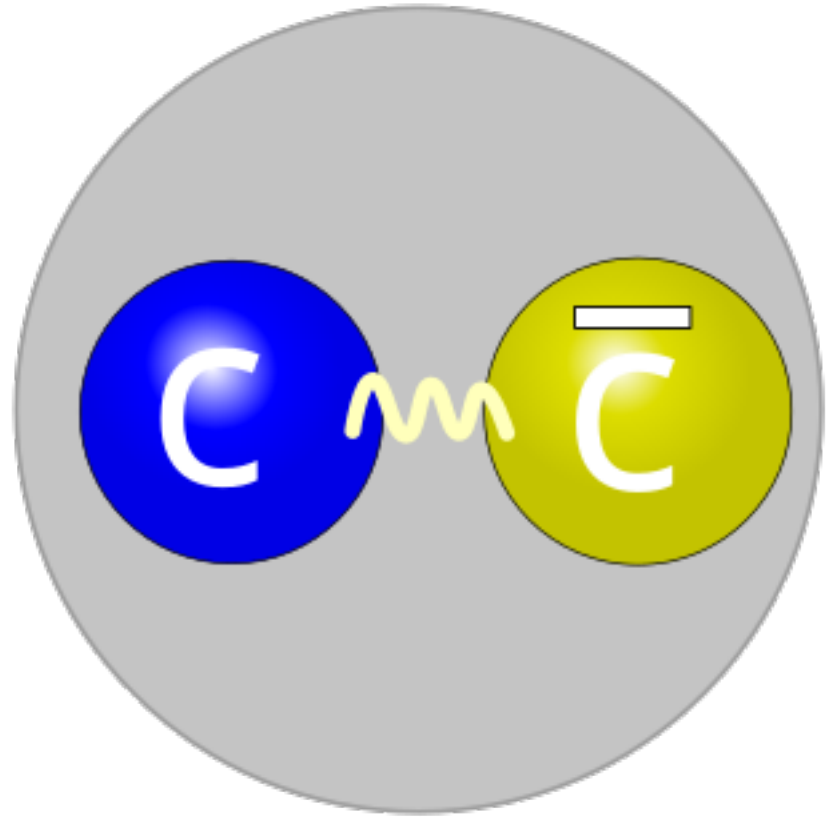
Sachs Form Factors (EM)

$$G_E^B(q^2) = F_1^B(q^2) + \frac{q^2}{4M_B^2} F_2^B(q^2)$$

$$G_M^B(q^2) = F_1^B(q^2) + F_2^B(q^2)$$



Charmonium Decays



Decay Length

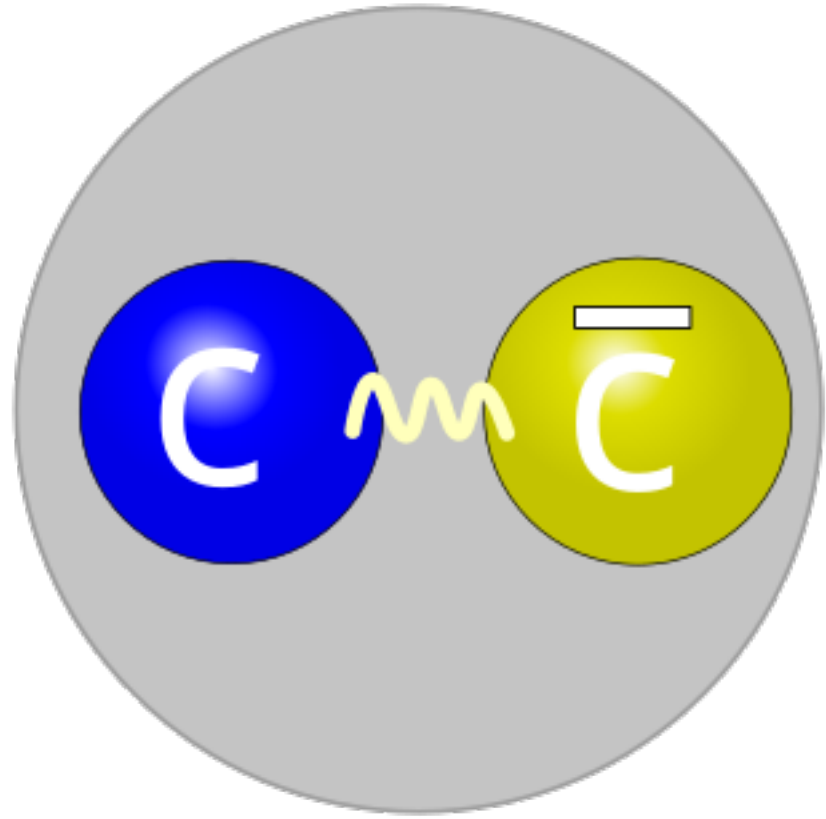
$$\Gamma_{B_1 B_2}^{\psi} = \beta_{B_1 B_2}(M_{\psi}^2) \Gamma_{\mu\mu}^{\psi} \left(\frac{2M_{B_1 B_2}^2}{M_{\psi}^2} \left| g_E^{B_1 B_2} \right|^2 + \left| g_M^{B_1 B_2} \right|^2 \right) = \beta_{B_1 B_2}(M_{\psi}^2) \Gamma_{\mu\mu}^{\psi} \left| A_{B_1 B_2}^{\psi} \right|^2$$

Branching Ratio

$$\text{BR}_{B_1 B_2}^{\gamma} = \frac{|g_{\gamma}^{\psi}|^2 \beta_{B_1 B_2}(M_{\psi}^2)}{16\pi M_{\psi} \Gamma_{\psi}} \left| A_{B_1 B_2}^{\gamma}(M_{\psi}^2) \right|^2$$

- Purely Em decay of the ψ is assumed;
- “Psionic” form factors coincide with EM ones at $q^2 = M_{\psi}^2$;
- The BR depends from the $\psi \rightarrow \gamma$ coupling, extracted from the decay into $\mu^+ \mu^-$.

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Decays of the ψ : parametrization 1/2

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

Symmetry-breaking effects

$$S_m = \frac{g_m}{3} \begin{pmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & -2 \end{pmatrix}$$

$$\begin{aligned} \mathcal{L}^0 = & g \operatorname{Tr} (\mathcal{B} \bar{\mathcal{B}}) + d \operatorname{Tr} (\{\mathcal{B}, \bar{\mathcal{B}}\} S_e) + f \operatorname{Tr} ([\mathcal{B}, \bar{\mathcal{B}}] S_e) \\ & + d' \operatorname{Tr} (\{\mathcal{B}, \bar{\mathcal{B}}\} S_m) + f' \operatorname{Tr} ([\mathcal{B}, \bar{\mathcal{B}}] S_m) \end{aligned}$$

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$$\operatorname{BR}_{B_1 B_2}^\gamma = \frac{|\vec{p}|}{8\pi M_\psi^2 \Gamma_\psi} \left| A_{B_1 B_2}^{ggg} + A_{B_1 B_2}^{gg\gamma} + A_{B_1 B_2}^\gamma \right|^2$$

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EM effect

Purely EM decay

Decays of the ψ : parametrization 2/2

$\mathcal{C}_{\text{strong}} = \{G_0, D_m, F_m\}$ Strong and mixed decays

$\mathcal{C}_{\text{EM}} = \{D_e, F_e\}$ EM decay

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$B\bar{B}$	$g_\psi^\gamma A_{B_1\bar{B}_2}^\gamma (M_\psi^2)$
$\Sigma^0\bar{\Sigma}^0$	D_e
$\Lambda\bar{\Lambda}$	$-D_e$
$\Lambda\bar{\Sigma}^0 + \text{c.c.}$	$\sqrt{3}D_e$
$n\bar{n}$	$-2D_e$
$\Xi^0\bar{\Xi}^0$	$-2D_e$
$\Sigma^-\bar{\Sigma}^+$	$D_e - F_e$
$\Sigma^+\bar{\Sigma}^-$	$D_e + F_e$
$\Xi^-\bar{\Xi}^+$	$D_e - F_e$
$p\bar{p}$	$D_e + F_e$

Decays of the ψ : parametrization 2/2

$$\mathcal{C}_{\text{strong}} = \{G_0, D_m, F_m\} \quad \text{Strong and mixed decays}$$

$$\mathcal{C}_{\text{EM}} = \{D_e, F_e\} \quad \text{EM decay}$$

Charmonium EM decays parametrized by a single coupling constant $\Rightarrow$ All amplitudes proportional to the decay into $\Lambda\bar{\Sigma}^0 + \text{c.c.}$

$$\text{BR}_{\Lambda\bar{\Sigma}^0}^\gamma = \frac{3|D_e|^2 \beta_{M_{\Lambda\bar{\Sigma}^0}}(M_\psi^2)}{16\pi M_\psi \Gamma_\psi}$$

$$\text{BR}_{B^0\bar{B}^0}^\gamma = \frac{N_{B^0\bar{B}^0}^2 \beta_{M_{B^0\bar{B}^0}}(M_\psi^2)}{\beta_{M_{\Lambda\bar{\Sigma}^0}}(M_\psi^2)} \text{BR}_{\Lambda\bar{\Sigma}^0}^\gamma$$

$$N_{B^0\bar{B}^0} = \begin{cases} -2/\sqrt{3} & B^0\bar{B}^0 = n \\ -1/\sqrt{3} & B^0 = \Lambda \\ 1/\sqrt{3} & B^0 = \Sigma^0 \\ -2/\sqrt{3} & B^0 = \Xi^0 \end{cases}$$

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σ from the branching ratio

- Cross section extracted directly from the BR of J/ψ e $\psi(2S) \rightarrow \Lambda\bar{\Sigma}^0 + \text{c.c.}$;
- Purely EM decay is assumed.
- We define a scaled cross section in order to compare data for all the neutral baryons.

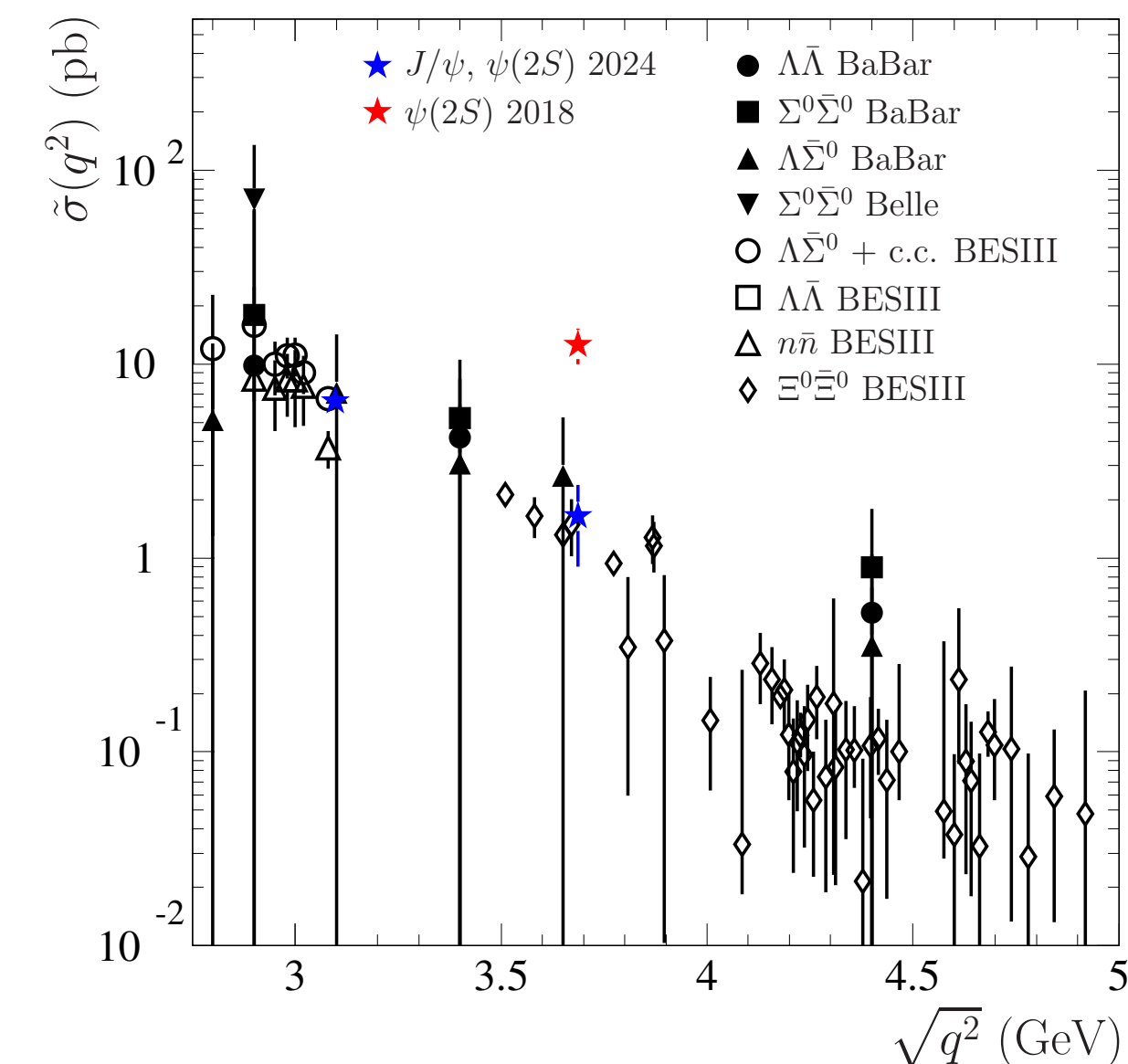
$$\text{BR}(J/\psi \rightarrow \Lambda\bar{\Sigma}^0 + \text{c.c.}) = (2.83 \pm 0.23) \times 10^{-5}$$

$$\text{BR}(\psi(2S) \rightarrow \Lambda\bar{\Sigma}^0 + \text{c.c.}) = (1.6 \pm 0.7) \times 10^{-6}$$

Phys. Rev. D **110**, 030001 (2024)

$$\text{BR}_{18}(\psi(2S) \rightarrow \Lambda\bar{\Sigma}^0 + \text{c.c.}) = (1.23 \pm 0.24) \times 10^{-5}$$

$$\tilde{\sigma}(q^2) = \frac{\sigma_{B^0\bar{B}^0}(q^2)}{N_{B^0\bar{B}^0}^2 \beta_{M_{B^0}}(q^2)} = \frac{4\pi\alpha^2}{3q^2} |A_{\Lambda\bar{\Sigma}^0}^\gamma(q^2)|^2$$



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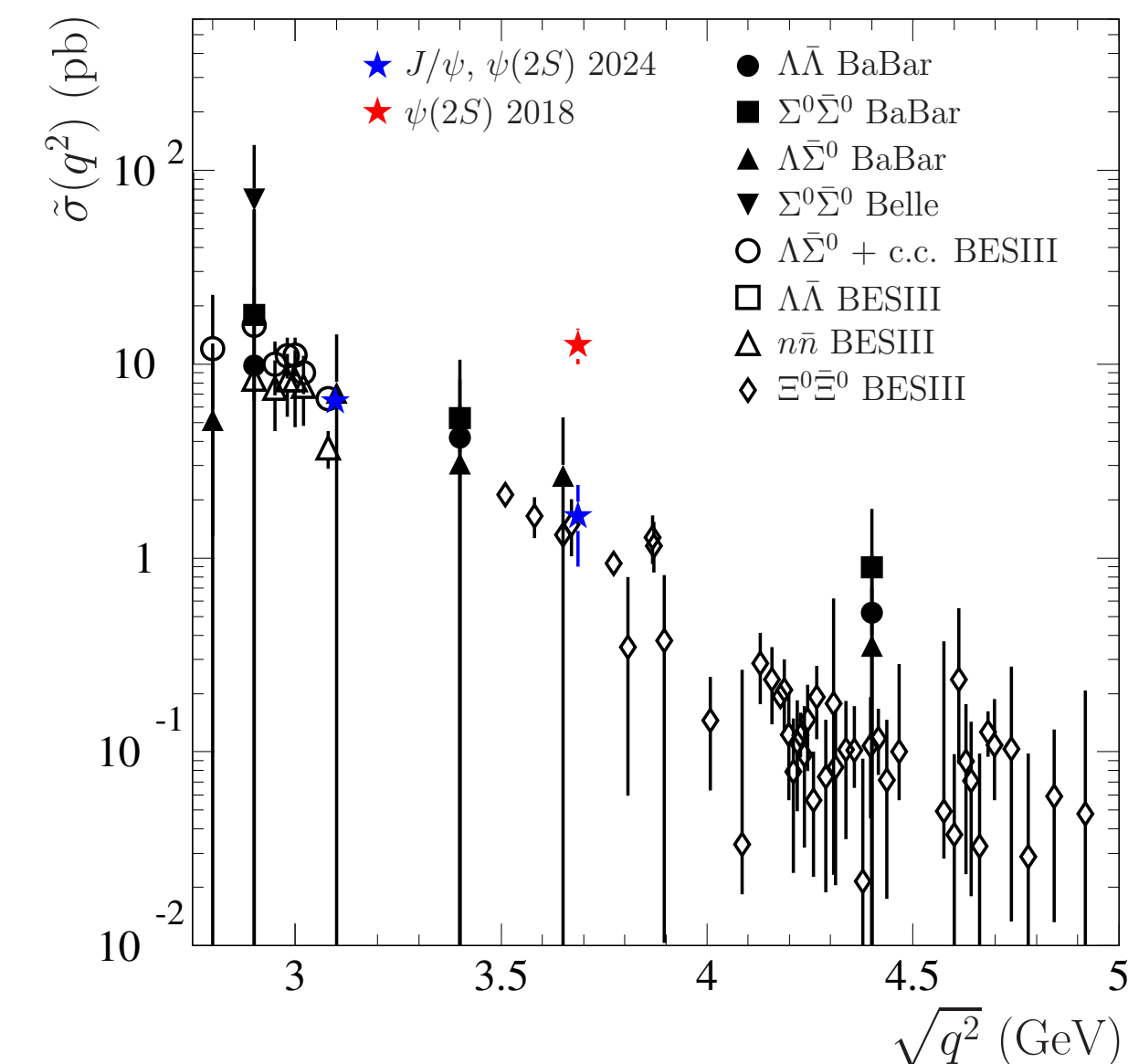
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$$\tilde{\sigma}_{\star}^{J/\psi} = (6.45 \pm 0.53) \text{ pb}$$

$$\tilde{\sigma}_{\star}^{\psi(2S)} = (1.64 \pm 0.74) \text{ pb} \quad \tilde{\sigma}_{18\star}^{\psi(2S)} = (12.6 \pm 2.6) \text{ pb}$$

$$\tilde{\sigma}(q^2) = \frac{\sigma_{B^0\bar{B}^0}(q^2)}{N_{B^0\bar{B}^0}^2 \beta_{M_{B^0}}(q^2)} = \frac{4\pi\alpha^2}{3q^2} |A_{\Lambda\bar{\Sigma}^0}^{\gamma}(q^2)|^2$$



Scaled cross section: global fit

- Baryon's cross section fit with pQCD-driven function;
- Asymptotic behaviour from the Phragmén-Lindelöf theorem;
- Logarithmic correction on the time-like region.

$$G_{E,M}^B(q^2) \sim (q^2)^{-2}, \quad q^2 \rightarrow \pm \infty$$

Recall

$$\sigma_{BB} = \frac{4\pi\alpha^2\beta_{M_B}(q^2)}{3q^2} |A_{B\bar{B}}^\gamma|^2$$

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$$\tilde{\sigma}_{\text{fit}}(q^2) = \frac{A}{(q^2)^5 \left(\pi^2 + \ln^2 \left(q^2 / \Lambda_{\text{QCD}}^2 \right) \right)^2}$$

- 70 data points analyzed;
- Lower limit on the C.O.M. energy $\sqrt{q_{\text{min}}^2} = 2.8 \text{ GeV}$.

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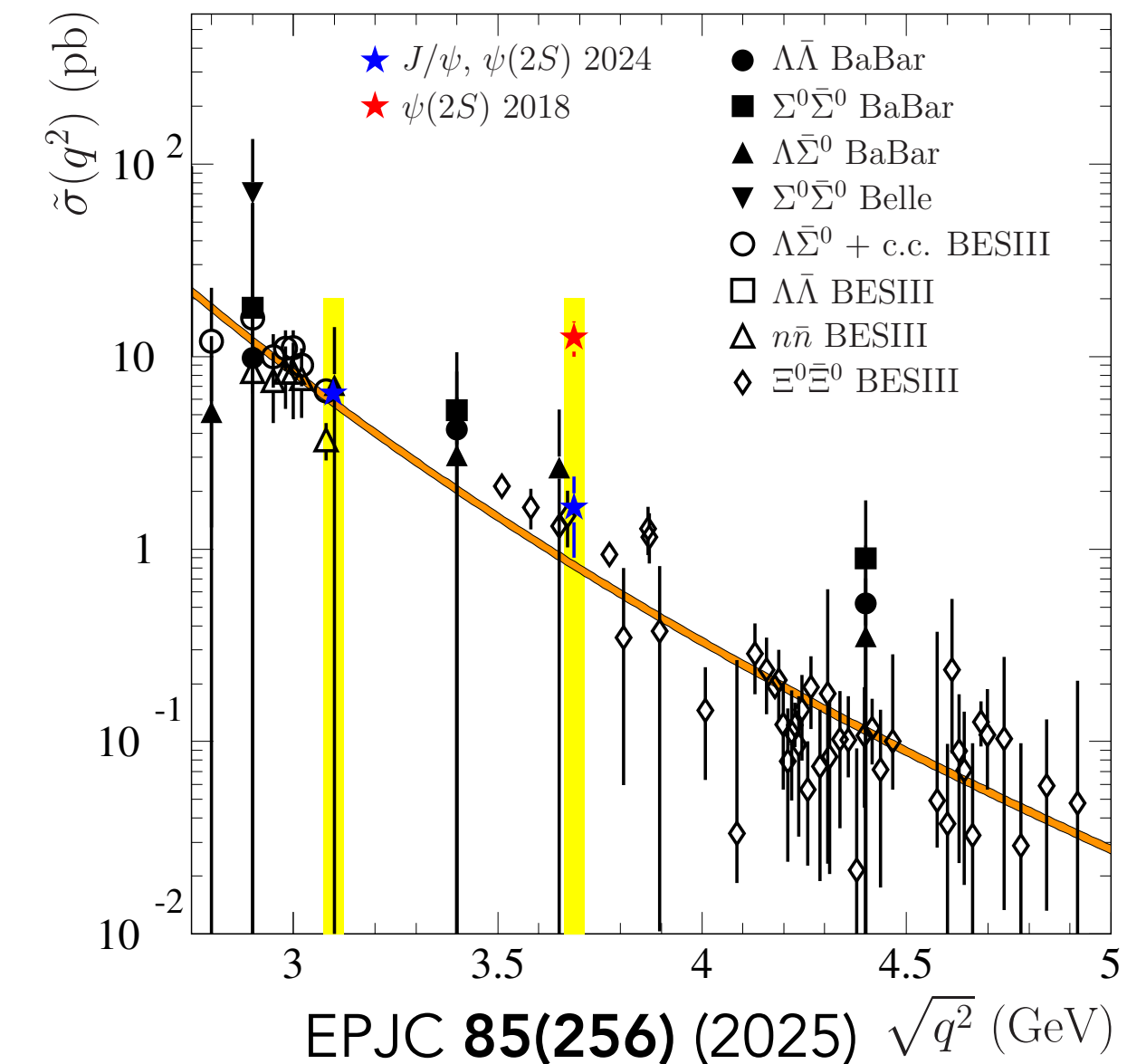
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$$\tilde{\sigma}_{\text{fit}}(M_{J/\psi}^2) = (5.79 \pm 0.30) \text{ pb} \quad \tilde{\sigma}_{\text{fit}}(M_{\psi(2S)}^2) = (0.825 \pm 0.043) \text{ pb}$$

$$G_{E,M}^B(q^2) \sim (q^2)^{-2}, \quad q^2 \rightarrow \pm \infty$$

Recall

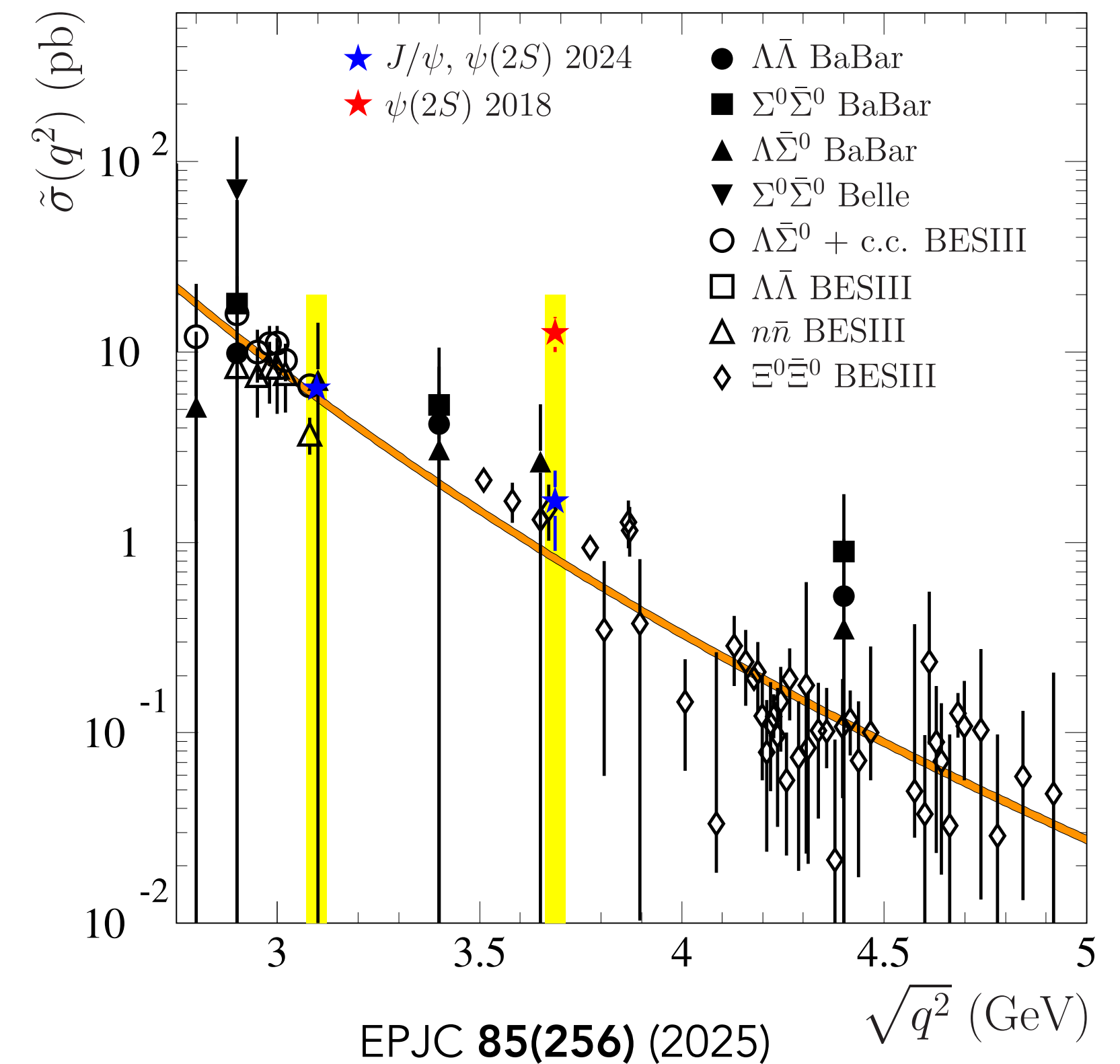
$$\sigma_{BB} = \frac{4\pi\alpha^2\beta_{M_B}(q^2)}{3q^2} |A_{B\bar{B}}^\gamma|^2$$



From the theory

$$\frac{\Gamma_{\Lambda\bar{\Sigma}^0}^{J/\psi}/\Gamma_{\mu\mu}^{J/\psi}}{\Gamma_{\Lambda\bar{\Sigma}^0}^{\psi(2S)}/\Gamma_{\mu\mu}^{\psi(2S)}} \simeq \left(\frac{M_{\psi(2S)}}{M_{J/\psi}} \right)^8 \simeq 4.0$$

- pQCD predicts a value of 4 for the ratio of BRs for J/ψ and $\psi(2S)$;
- Comparaison of 2018 (CLEO) and 2024 (BESIII) data.



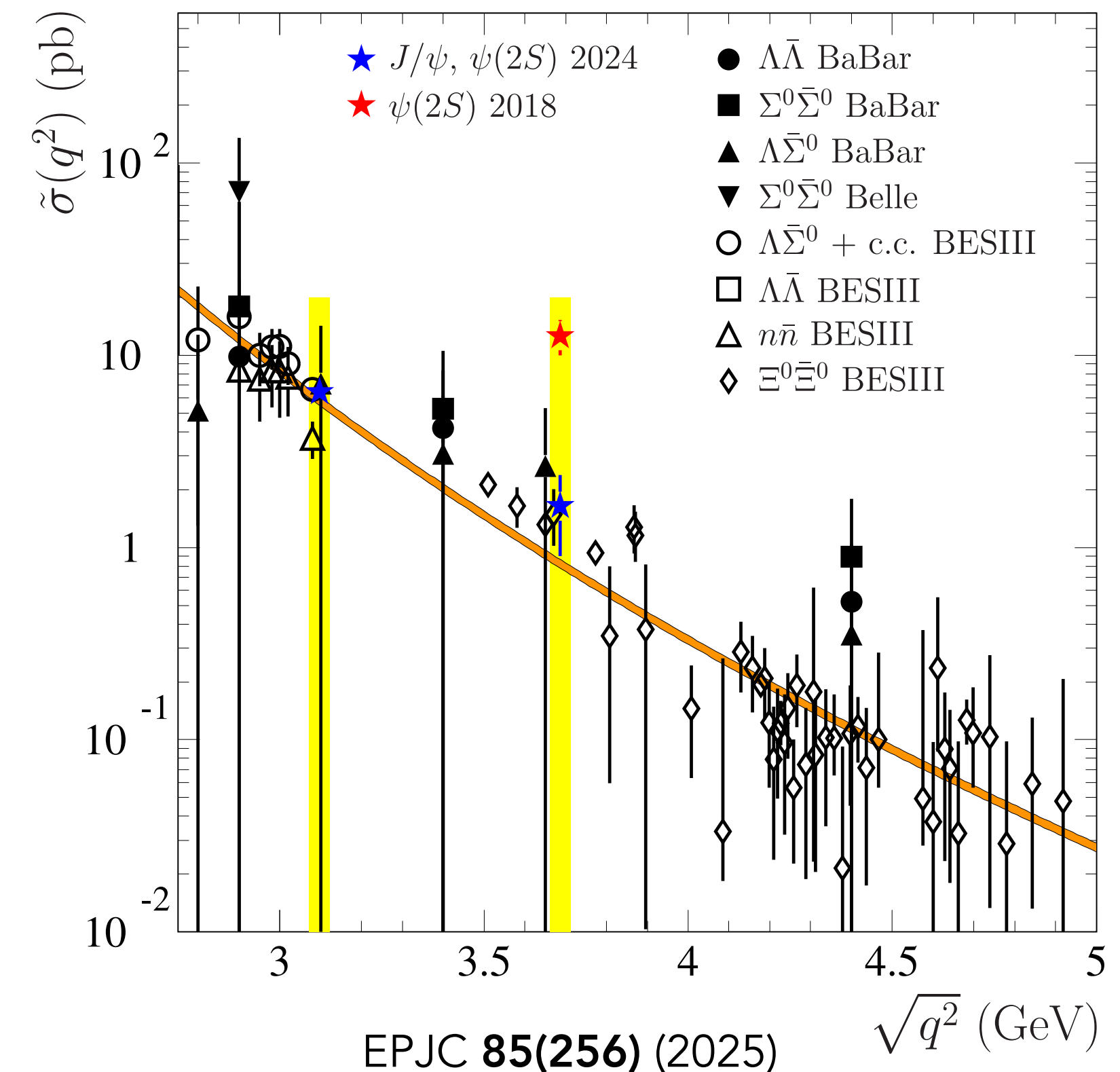
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$$\frac{\Gamma_{\Lambda\bar{\Sigma}^0}^{J/\psi}/\Gamma_{\mu\mu}^{J/\psi}}{\Gamma_{\Lambda\bar{\Sigma}^0}^{\psi(2S)}/\Gamma_{\mu\mu}^{\psi(2S)}} = \begin{cases} 0.31 \pm 0.07 & 2018 \\ 2.4 \pm 1.0 & 2024 \end{cases}$$

- 2018 value is less than 1!



Isospin-violating effect 1/2

- What if we consider an isospin-violating contribution?
- Isospin conserved $\Rightarrow$ psionic FFs and EMFFs coincide at $q^2 = M_\psi^2$.

$$g_{E,M}^{B_1 B_2} = G_{E,M}^{B_1 B_2}(M_\psi^2)$$

- No further assumptions on the cross section $\Rightarrow$ NOT AFFECTED BY ISOSPIN-VIOLATION;
- BR measured assuming isospin conservation $\Rightarrow$ AFFECTED BY ISOSPIN-VIOLATION.

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- We define the ratio $R_{B_1 B_2}^\psi$:

$$R_{B_1 B_2}^\psi = \left| A_{B_1 B_2}^\gamma(M_\psi^2) + A_{B_1 B_2}^I \right| / \left| A_{B_1 B_2}^\gamma(M_\psi^2) \right|$$

Dependence over a relative phase

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Dependence over a relative phase

Study of $R_{B_1 B_2}^\psi$ as a function of the relative phase $\phi_{B_1 B_2}^\psi$!

Isospin-violating effect 2/2

- $R_{B_1 B_2}^\psi$ as a function of the relative phase;

$$|A_{B_1 B_2}^\gamma(M_\psi^2) + A_{B_1 B_2}^I|^2 = |A_{B_1 B_2}^\gamma(M_\psi^2)|^2 + |A_{B_1 B_2}^I|^2 + 2|A_{B_1 B_2}^\gamma(M_\psi^2)||A_{B_1 B_2}^I|\cos\left(\phi_{B_1 B_2}^\psi\right)$$

$$|A_{B_1 B_2}^I|/|A_{B_1 B_2}^\gamma(M_\psi^2)| = \sqrt{\left(R_{B_1 B_2}^\psi\right)^2 - \sin^2\left(\phi_{B_1 B_2}^\psi\right)} - \cos\left(\phi_{B_1 B_2}^\psi\right)$$

- Values of $R_{B_1 B_2}^\psi$ extracted from the cross section fit.

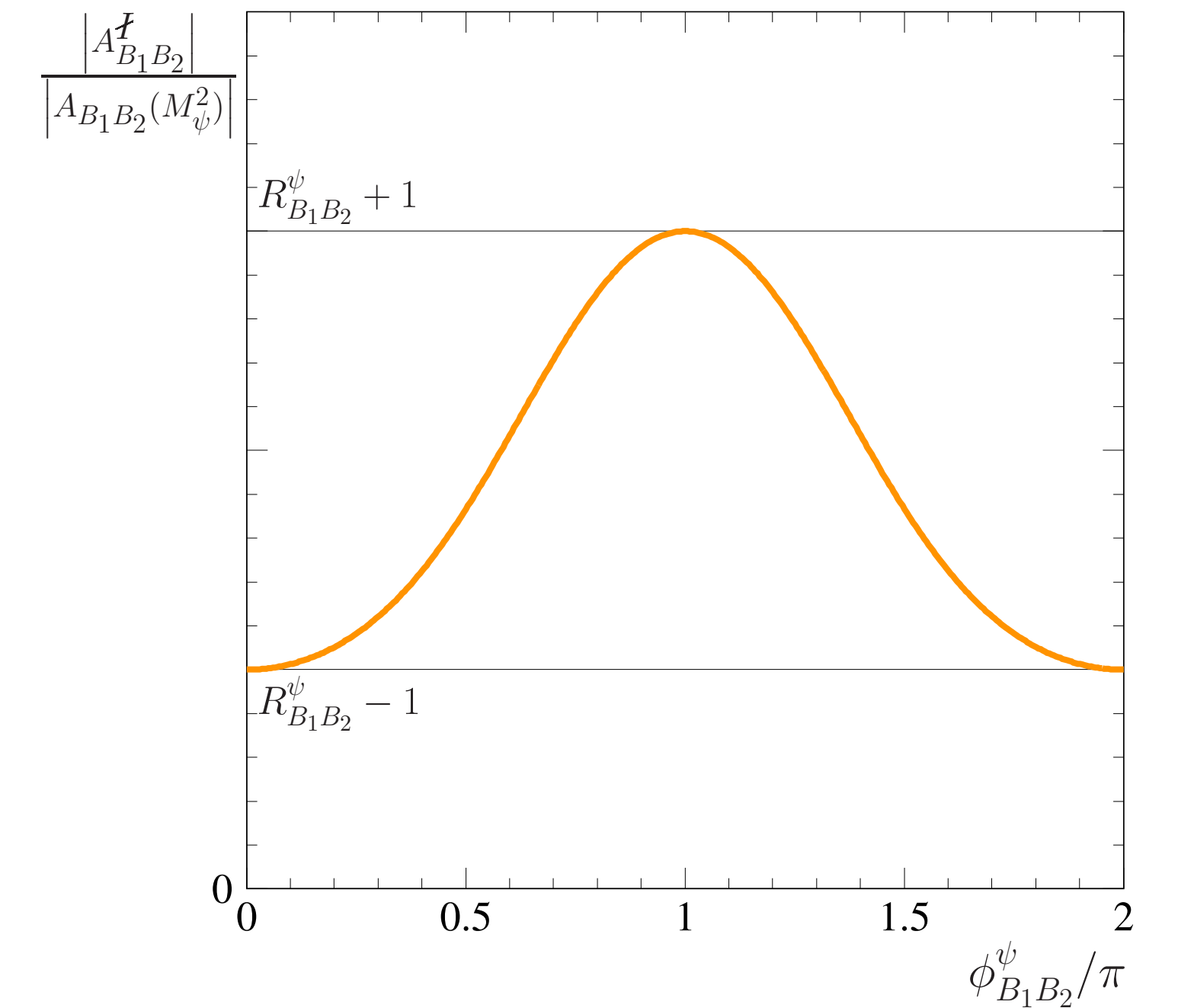
Isospin-violating effect 2/2

- $R_{B_1 B_2}^\psi$ as a function of the relative phase;

$$|A_{B_1 B_2}^\gamma(M_\psi^2) + A_{B_1 B_2}^I|^2 = |A_{B_1 B_2}^\gamma(M_\psi^2)|^2 + |A_{B_1 B_2}^I|^2 + 2|A_{B_1 B_2}^\gamma(M_\psi^2)||A_{B_1 B_2}^I|\cos\left(\phi_{B_1 B_2}^\psi\right)$$

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Isospin strikes back 1/2

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Isospin strikes back 1/2

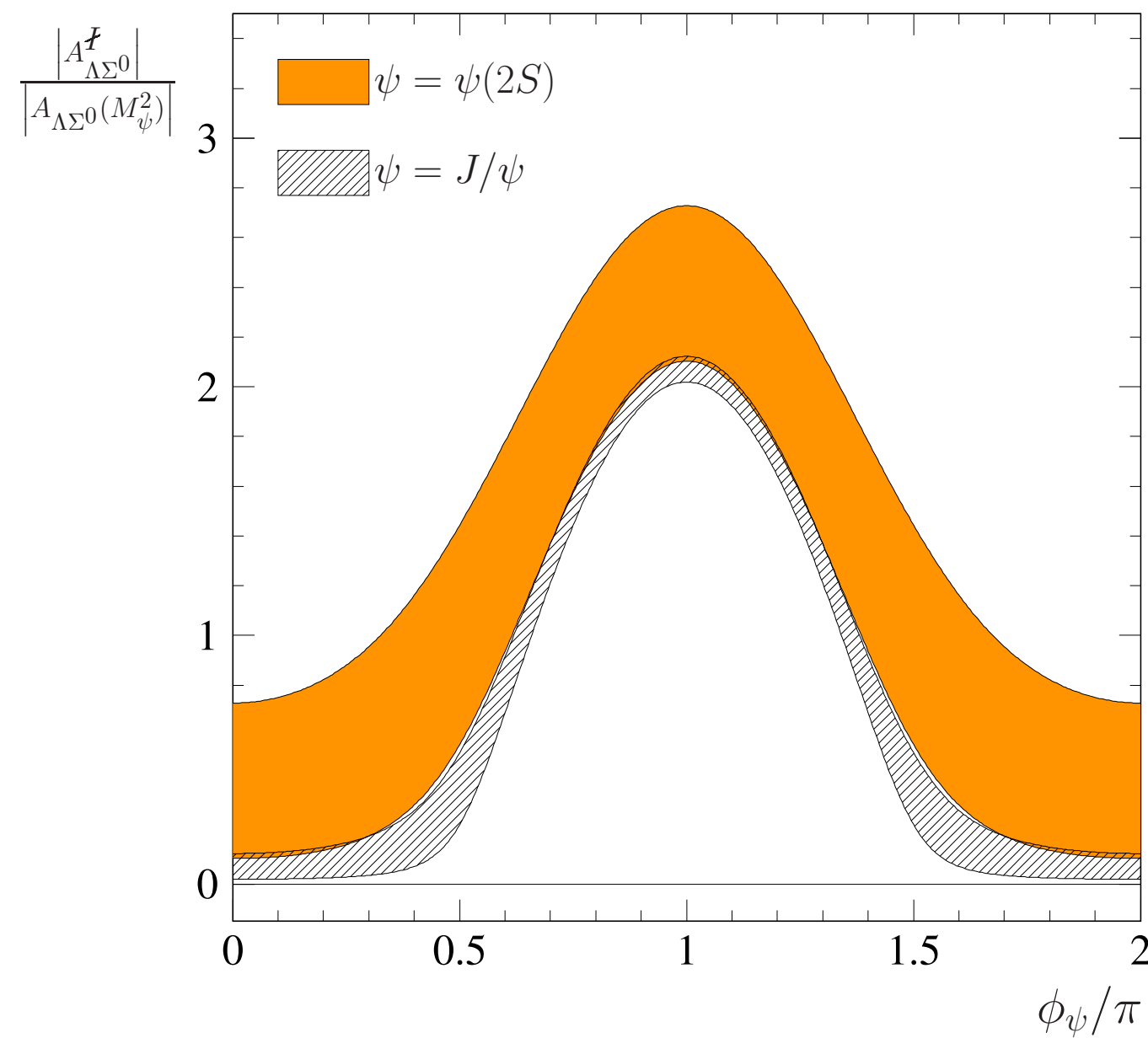
- Values of $R_{B_1 B_2}^\psi$ extracted from the cross section fit.

$$\left(R_{\Lambda\bar{\Sigma}^0}^\psi\right)^2 = \frac{4\pi\alpha^2}{3M_\psi^2\Gamma_{\mu\mu}^\psi} \frac{\Gamma_{\Lambda\bar{\Sigma}^0}^\psi}{\beta_{\Lambda\bar{\Sigma}^0}(M_\psi^2)\tilde{\sigma}_{\text{fit}}(M_\psi^2)} = \begin{cases} 1.15 \pm 0.11 & \psi = J/\psi \\ 2.00 \pm 0.88 & \psi = \psi(2S) \end{cases}$$

Isospin strikes back 1/2

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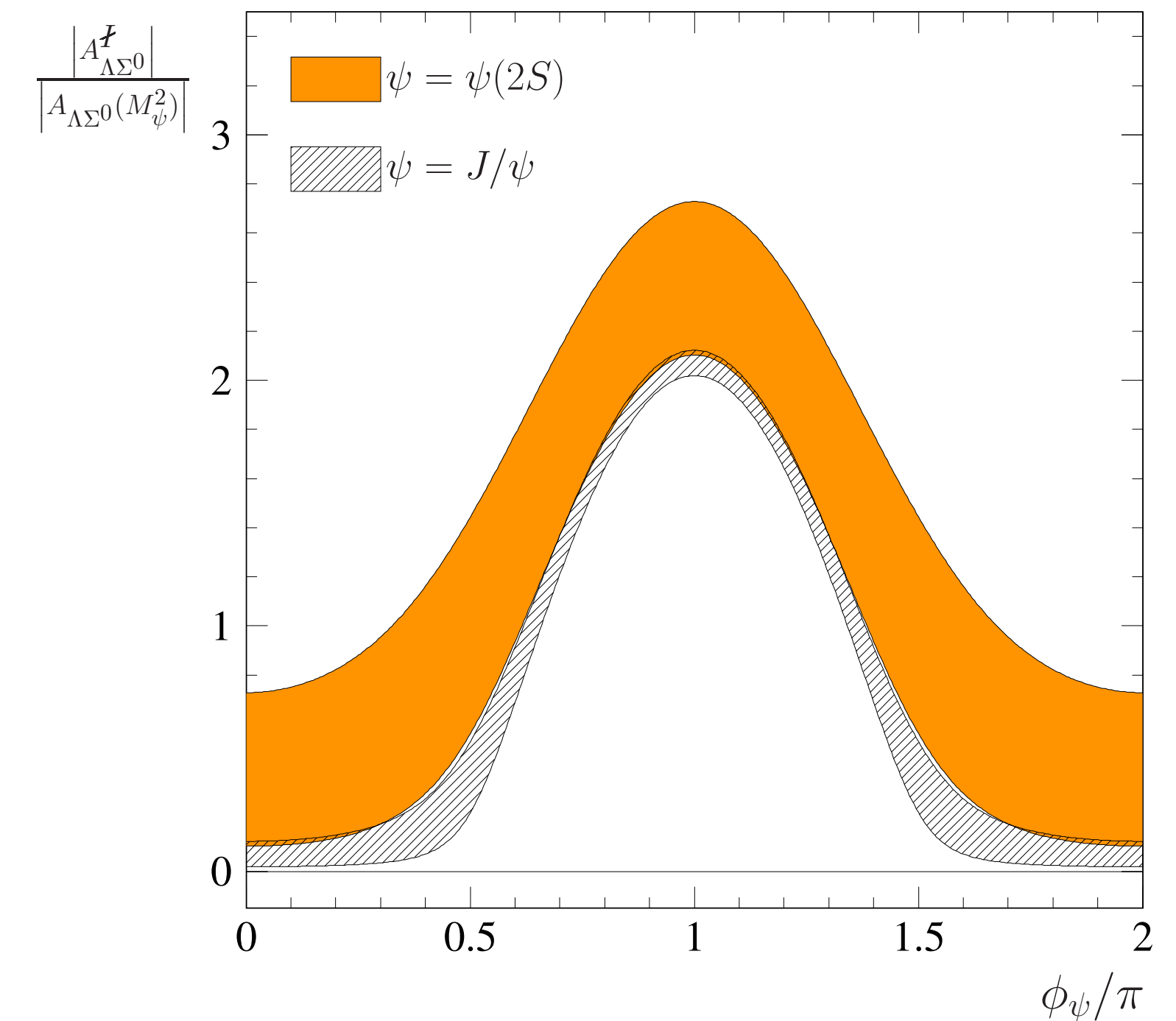


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- Minimum = $R_{\Lambda\bar{\Sigma}^0}^\psi - 1$ at $\phi_{\Lambda\bar{\Sigma}^0}^\psi = \{0, 2\pi\} \Rightarrow$ iso-violating and iso-conserving amplitudes have the same sign;
- Maximum = $R_{\Lambda\bar{\Sigma}^0}^\psi + 1$ at $\phi_{\Lambda\bar{\Sigma}^0}^\psi = \pi \Rightarrow$ iso-violating and iso-conserving amplitudes have opposed sign.

Isospin strikes back 2/2

- Magnitude of the isospin-violating contribution from the distance of $R_{\Lambda\bar{\Sigma}^0}^\psi$ from unity;
- Minima form the fit.



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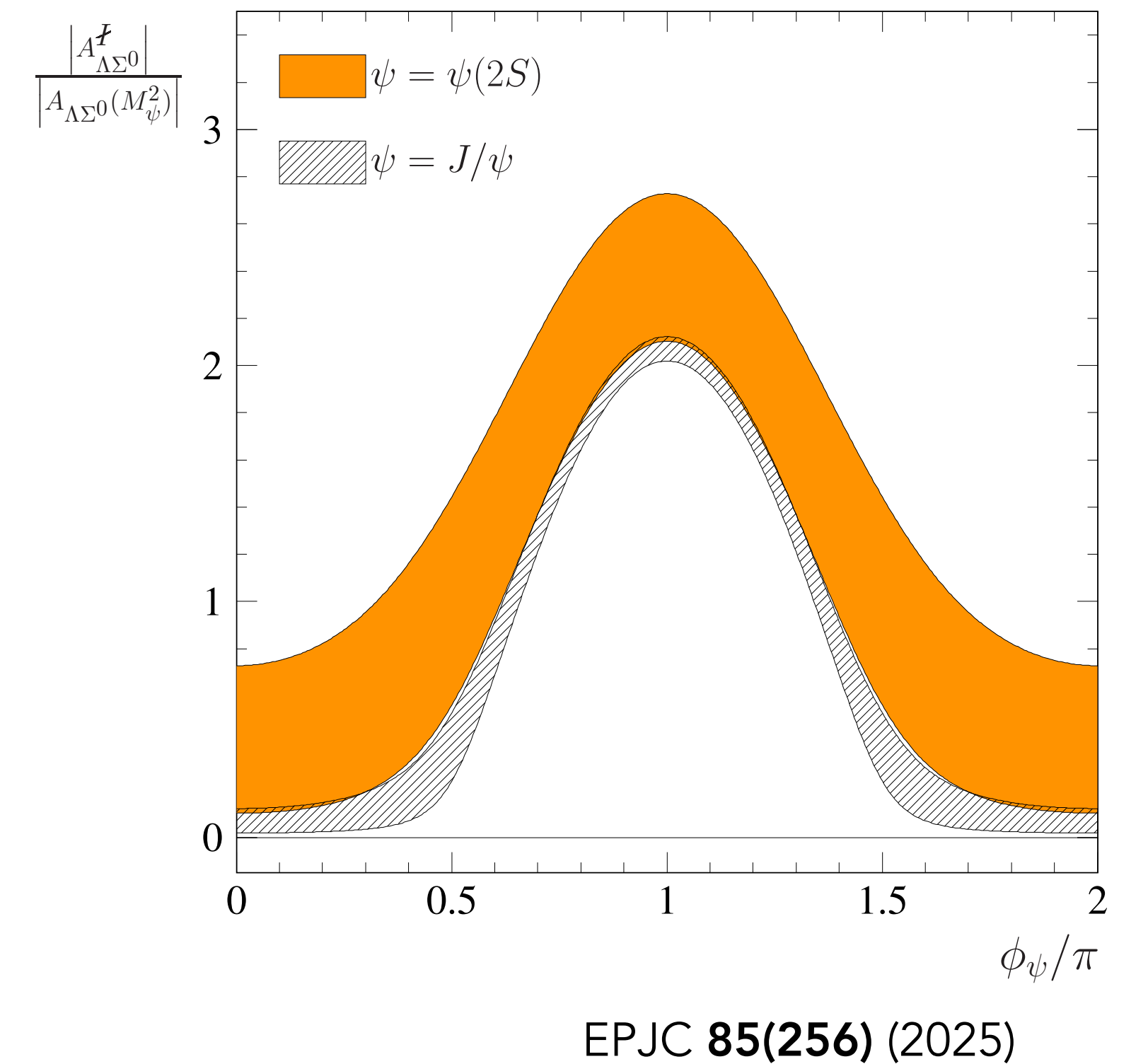
Isospin strikes back 2/2

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$$\left. \frac{|A_{\Lambda\bar{\Sigma}^0}^I|}{|A_{\Lambda\bar{\Sigma}^0}^{\gamma}(M_{\psi(2S)}^2)|} \right|_{\phi_{\Lambda\bar{\Sigma}^0}^{\psi(2S)}=0} = R_{\Lambda\bar{\Sigma}^0}^{\psi(2S)} - 1 = 0.41 \pm 0.31$$

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Both results comparable with zero!



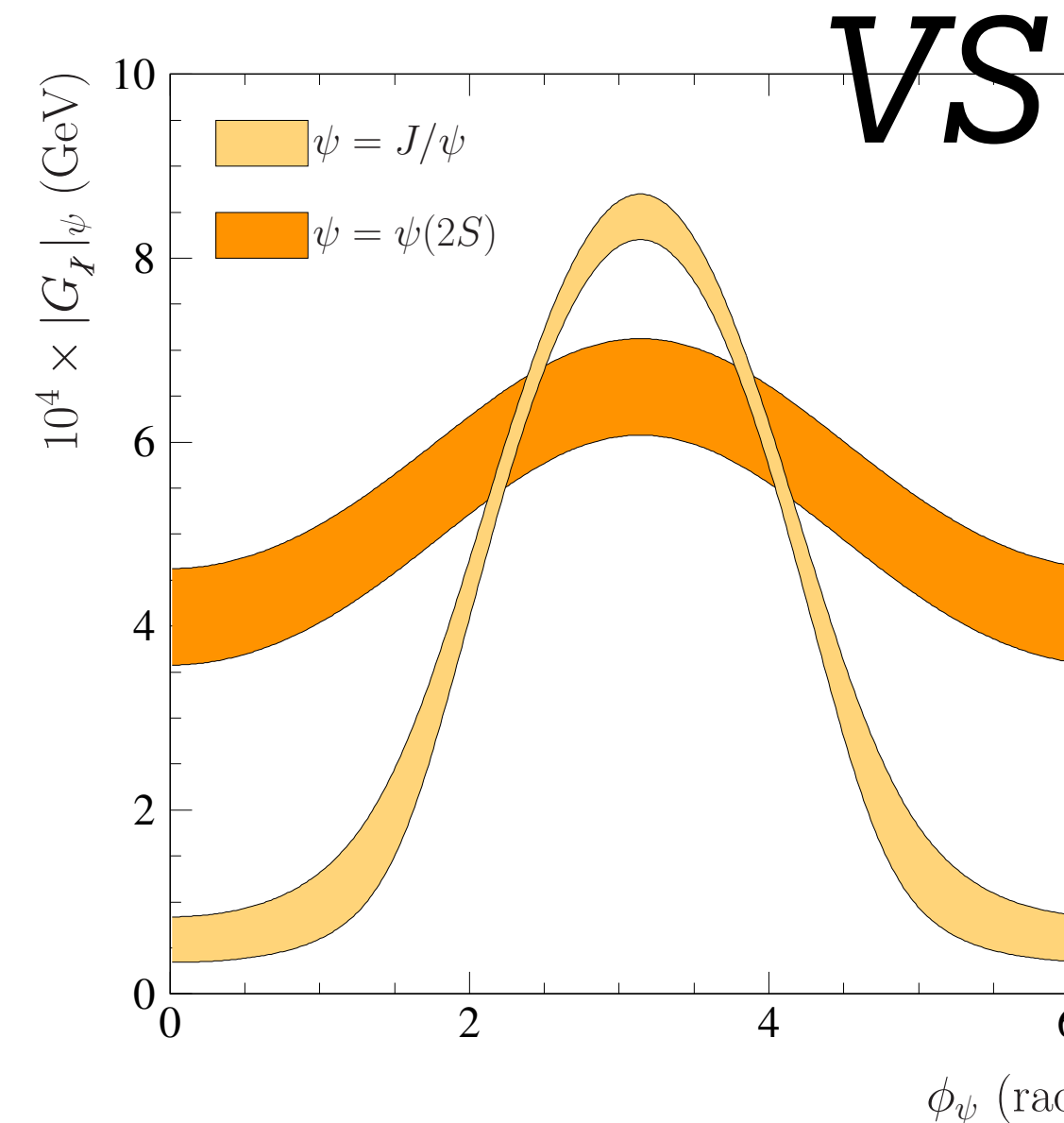
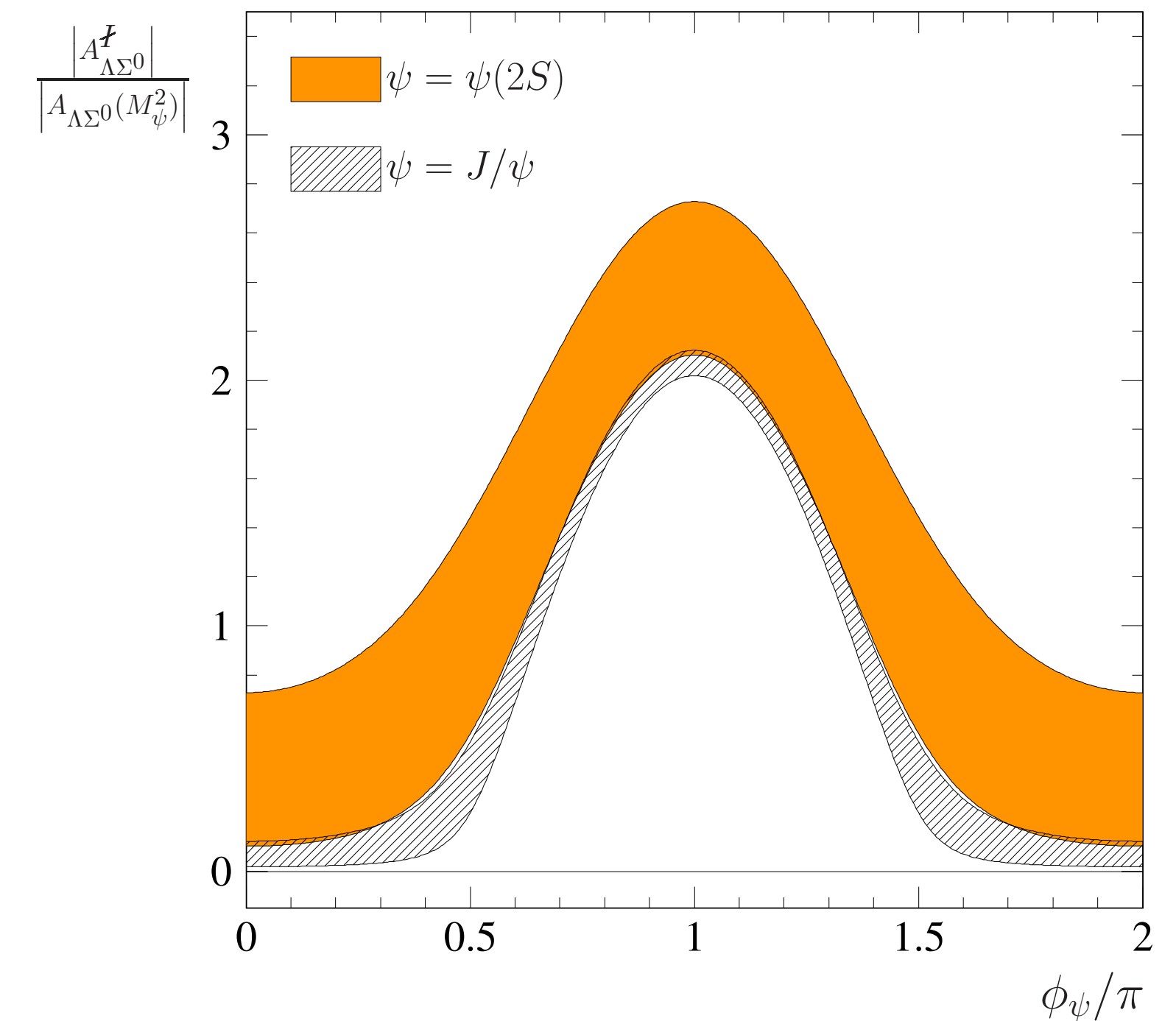
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EPJC **85(256)** (2025)

EPJC **80(9)** (2020)

Summary

- The new BESIII measurement excludes the presence of spectacular isospin-violating effects in $\psi \rightarrow \Lambda \bar{\Sigma}^0 + \text{c.c.}$ decays;
- The possibility of isospin violation of a few % remains;.

Summary



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**THANKS FOR YOUR
ATTENTION**