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ISOSPIN STRIKES BACK

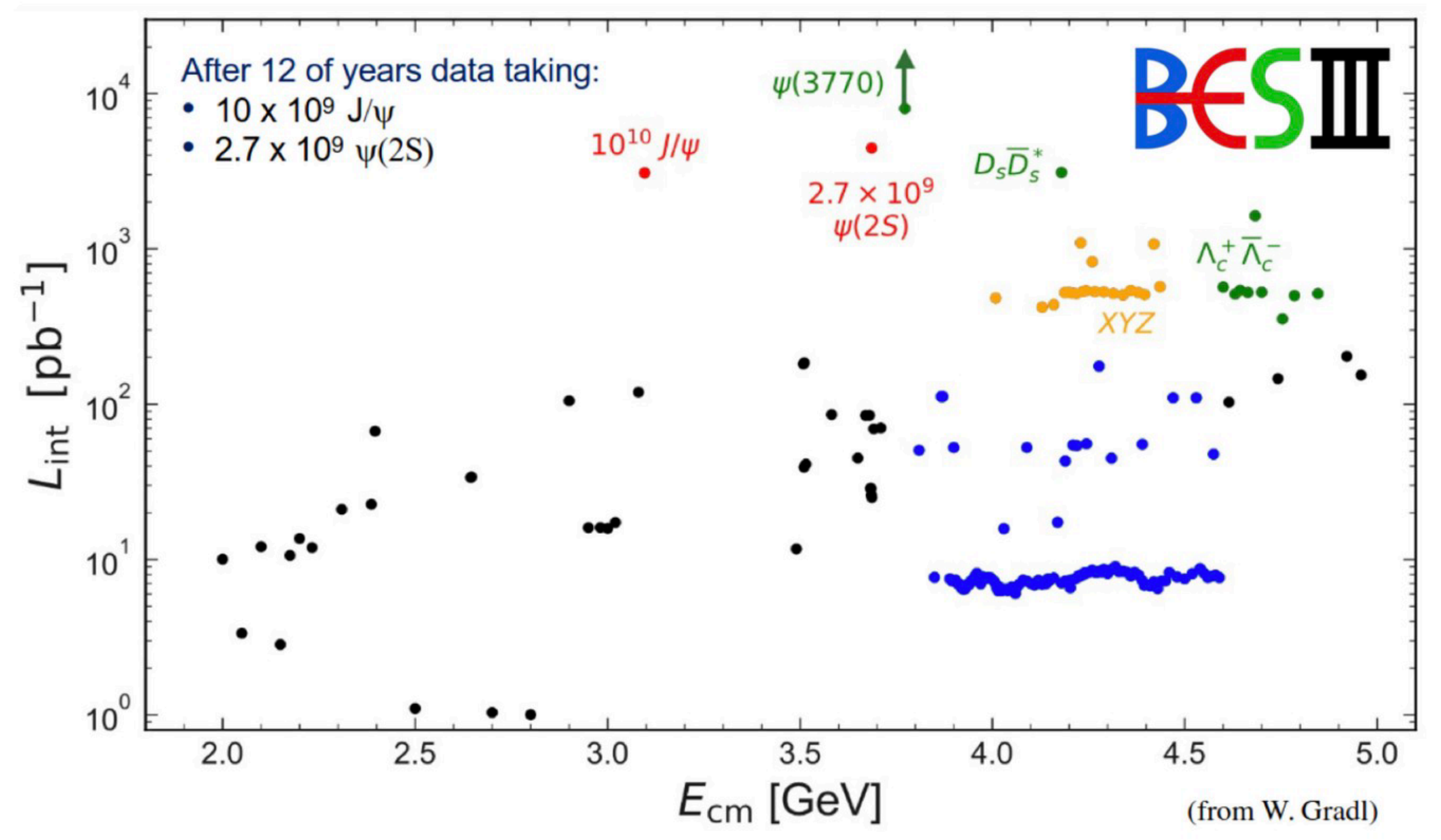
New Frontiers in Theoretical Physics - XXXVIII Convegno Nazionale di Fisica Teorica

Cortona 20-23/05/2025

OUTLINE

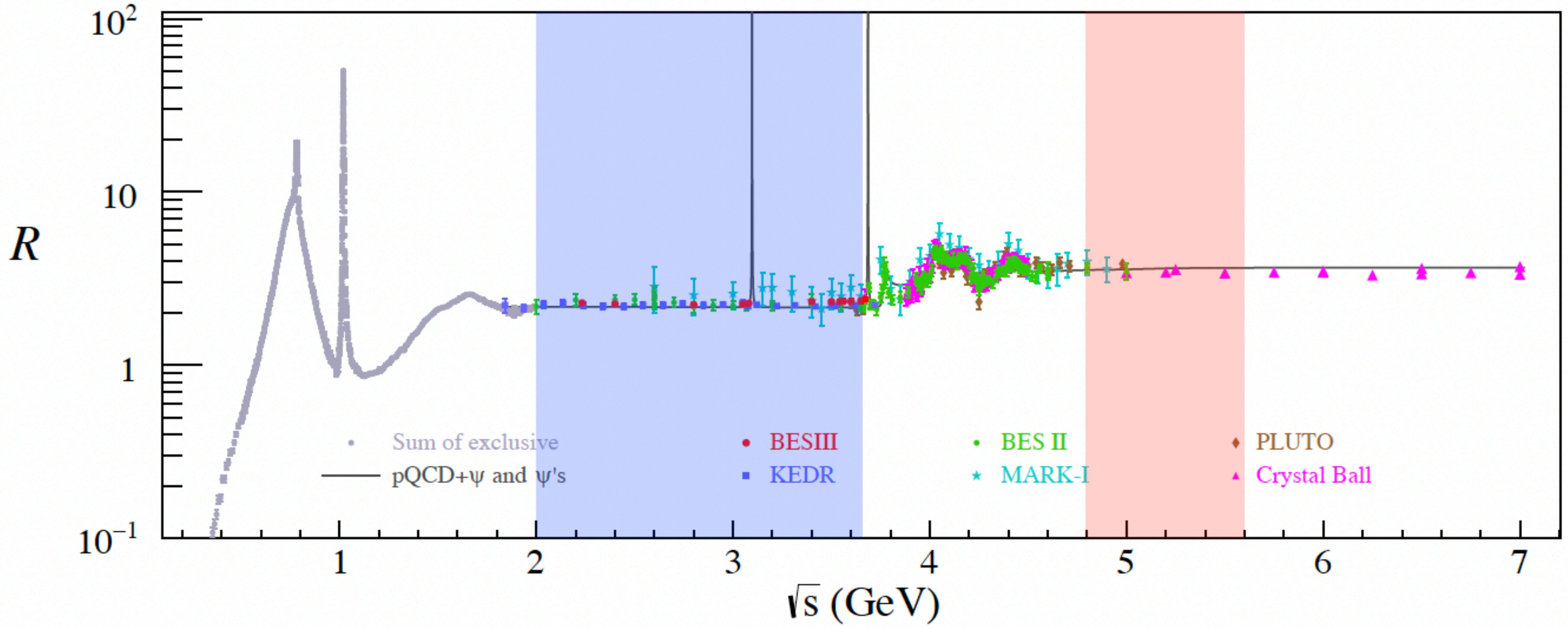
- Introduction to Electromagnetic Form Factors and ψ decays
- Scaled cross section and parameter extraction
- Isospin-violating contributes
- Results and discussion

BESIII DATASETS



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

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



- 10^{10} J/ψ and 2.7×10^9 $\psi(2S)$ 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

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

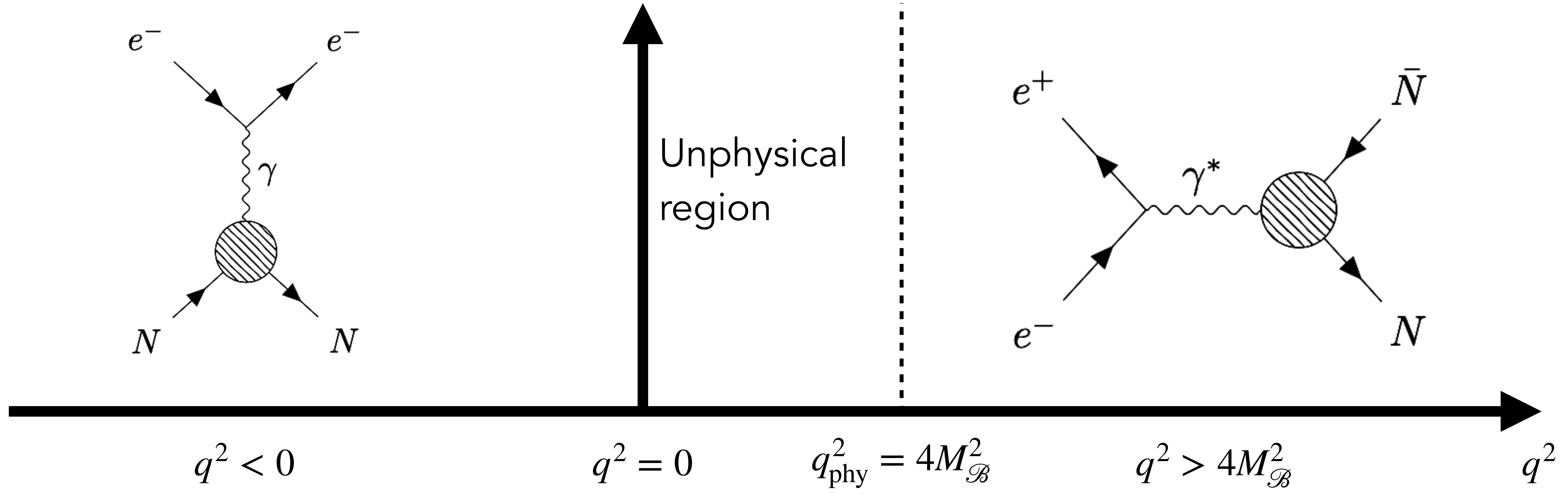
Sachs Form Factors (EM)

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

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

Cross section

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



ELECTROMAGNETIC FORM FACTORS

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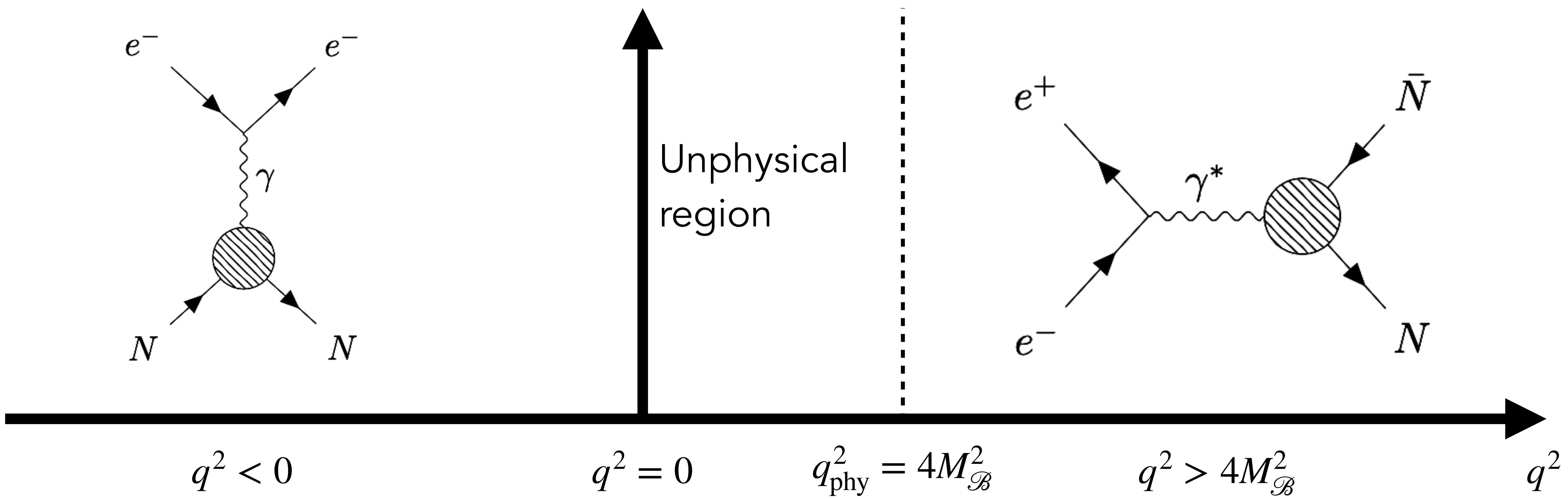
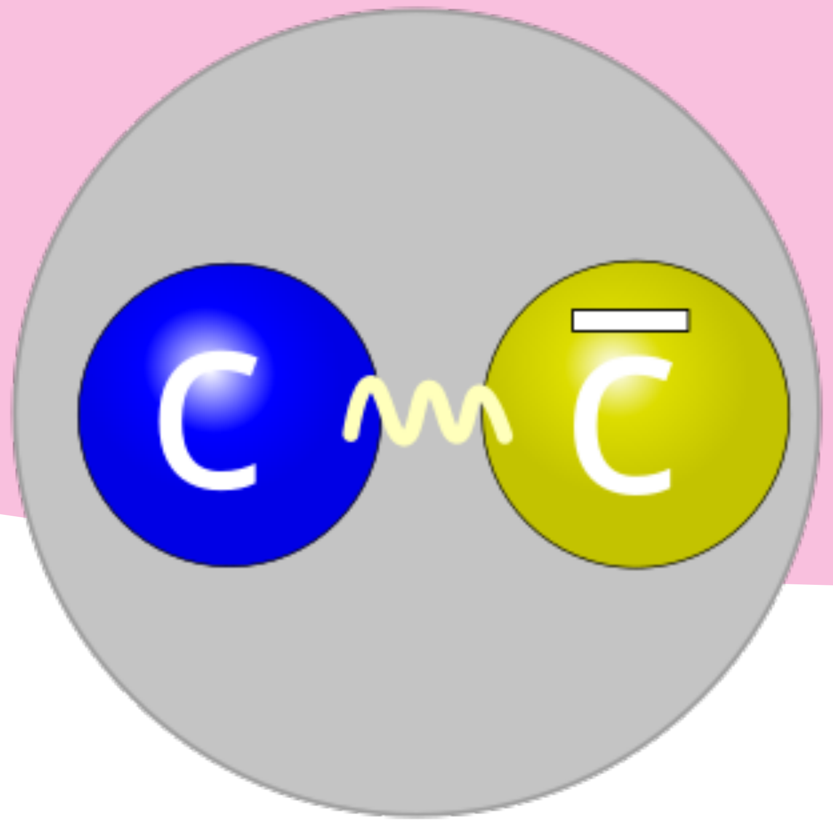


CHARMONIUM DECAYS



Decay Length

$$\Gamma^{\psi}_{B_1B_2} = \beta_{B_1B_2}(M_\psi^2)\Gamma^{\psi}_{\mu\mu}\left(\frac{2M^2_{B_1B_2}}{M_\psi^2}\left|g_E^{B_1B_2}\right|^2 + \left|g_M^{B_1B_2}\right|^2\right) = \beta_{B_1B_2}(M_\psi^2)\Gamma^{\psi}_{\mu\mu}\left|A^{\psi}_{B_1B_2}\right|^2$$

Branching Ratio

$$\mathrm{BR}^{\gamma}_{B_1B_2} = \frac{|g^{\psi}_{\gamma}|^2\,\beta_{M_{B_1B_2}}(M_\psi^2)}{16\pi M_\psi \Gamma_\psi}\,|A^{\gamma}_{B_1B_2}(M_\psi^2)|^2$$

- 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 $\psi \to \gamma$ coupling, extracted from the decay into $\mu^+\mu^-$.

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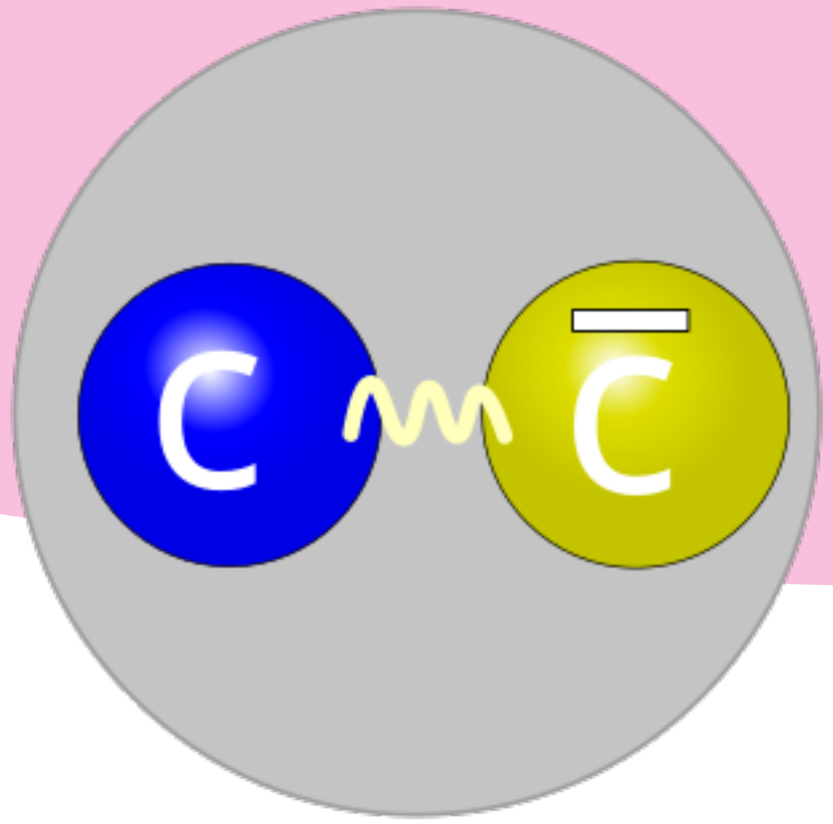

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DECAYS OF THE Ψ: PARAMETRIZATION 1/2

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

$$\mathcal{L}^0 = g\,\mathrm{Tr}\left(\mathcal{B}\bar{\mathcal{B}}\right) + d\,\mathrm{Tr}\left(\{\mathcal{B},\bar{\mathcal{B}}\}S_e\right) + f\,\mathrm{Tr}\left([\mathcal{B},\bar{\mathcal{B}}]S_e\right) + d'\,\mathrm{Tr}\left(\{\mathcal{B},\bar{\mathcal{B}}\}S_m\right) + f'\,\mathrm{Tr}\left([\mathcal{B},\bar{\mathcal{B}}]S_m\right)$$

$$\mathrm{BR}^{\gamma}_{B_1B_2} = \frac{|\vec{p}\,|}{8\pi M_\psi^2 \Gamma_\psi} \left| A^{ggg}_{B_1B_2} + A^{gg\gamma}_{B_1B_2} + A^{\gamma}_{B_1B_2} \right|^2$$

Symmetry-breaking effects

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

$$S_e = \frac{g_e}{3}\begin{pmatrix} 2 & 0 & 0 \\ 0 & -1 & 0 \\ 0 & 0 & -1 \end{pmatrix}$$

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Decays of the Ψ: Parametrization 2/2

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

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

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$B\bar{B}$	$g_\psi^\gamma A^\gamma_{B_1\bar{B}_2}(M_\psi^2)$
$\Sigma^0\bar{\Sigma}^0$	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

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

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

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

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

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

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

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CROSS SECTION FROM THE BRANCHING RATIO

- Cross section extracted directly from the BR of J/ψ e $\psi(2S) \to \Lambda\bar{\Sigma}^0 + \mathrm{c.c.}$;
- Purely EM decay is assumed.

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

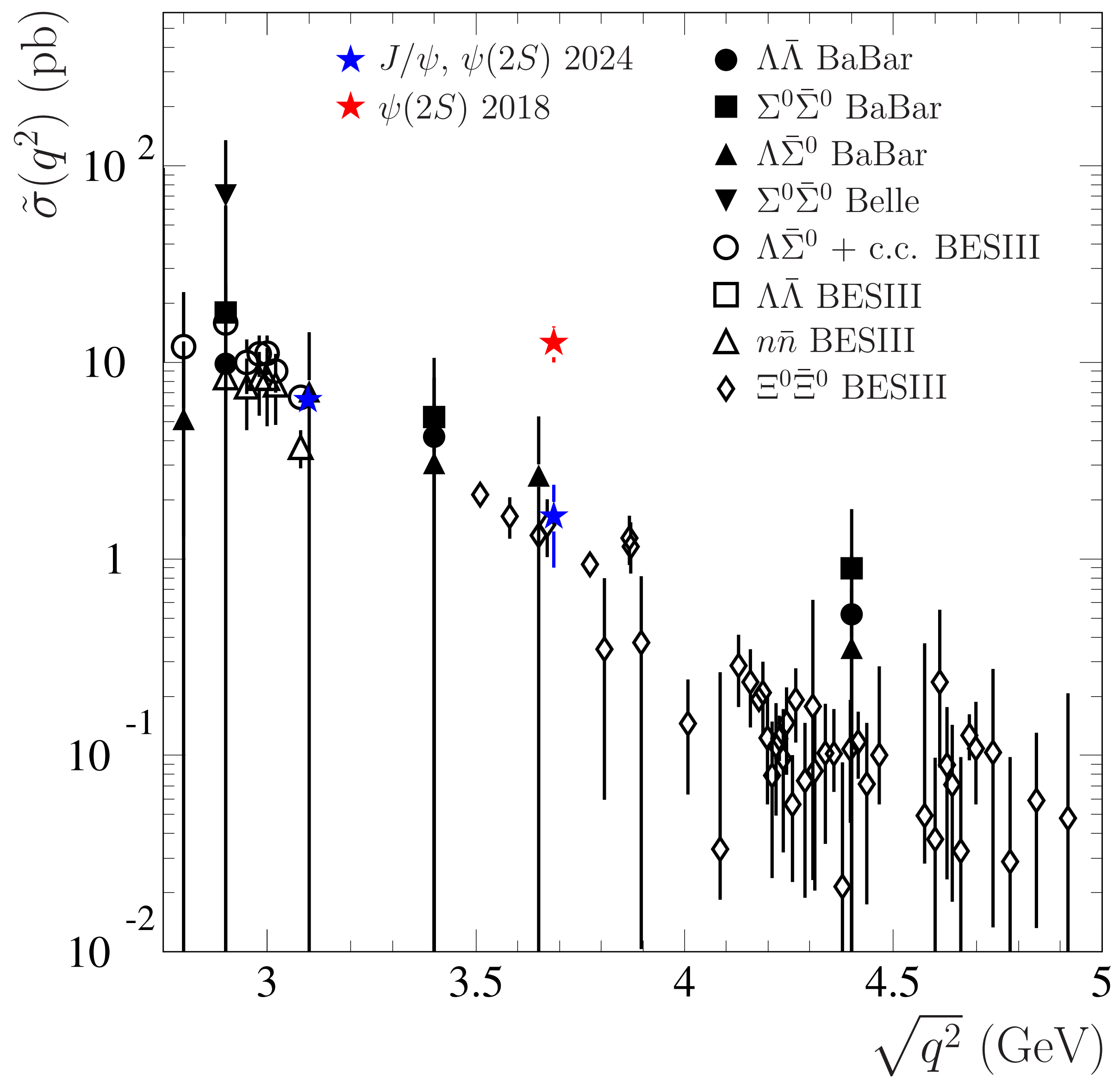
$$\mathrm{BR}(\psi(2S) \to \Lambda\bar{\Sigma}^0 + \mathrm{c.c.}) = (1.6 \pm 0.7) \times 10^{-6}$$

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

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

- We define a scaled cross section in order to compare data for all the neutral baryons.

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



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

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

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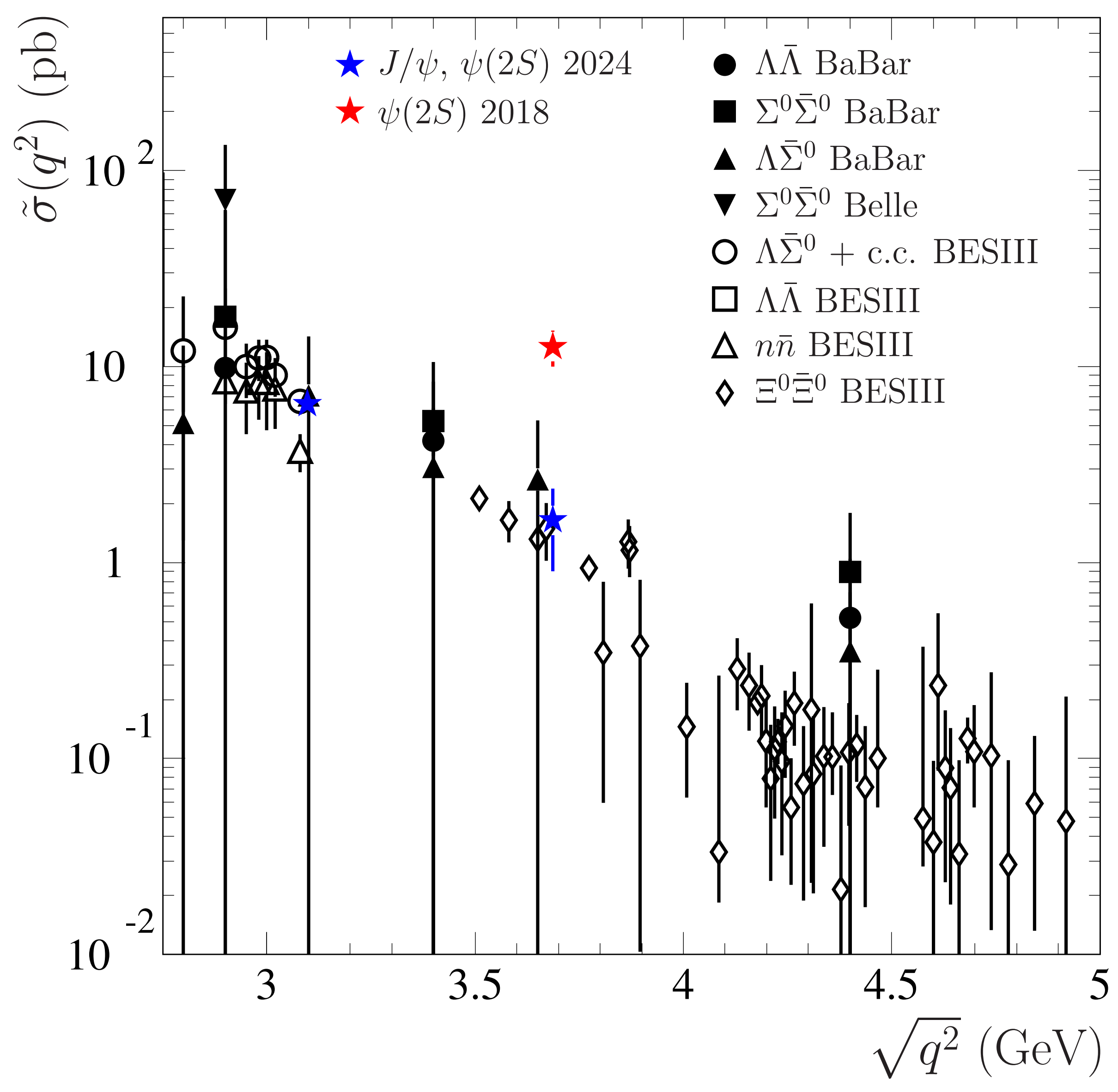

SCALED CROSS SECTION: GLOBAL FIT

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

$$G^B_{E,M}(q^2) \sim (q^2)^{-2},\ q^2 \to \pm\infty$$

Recall

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

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

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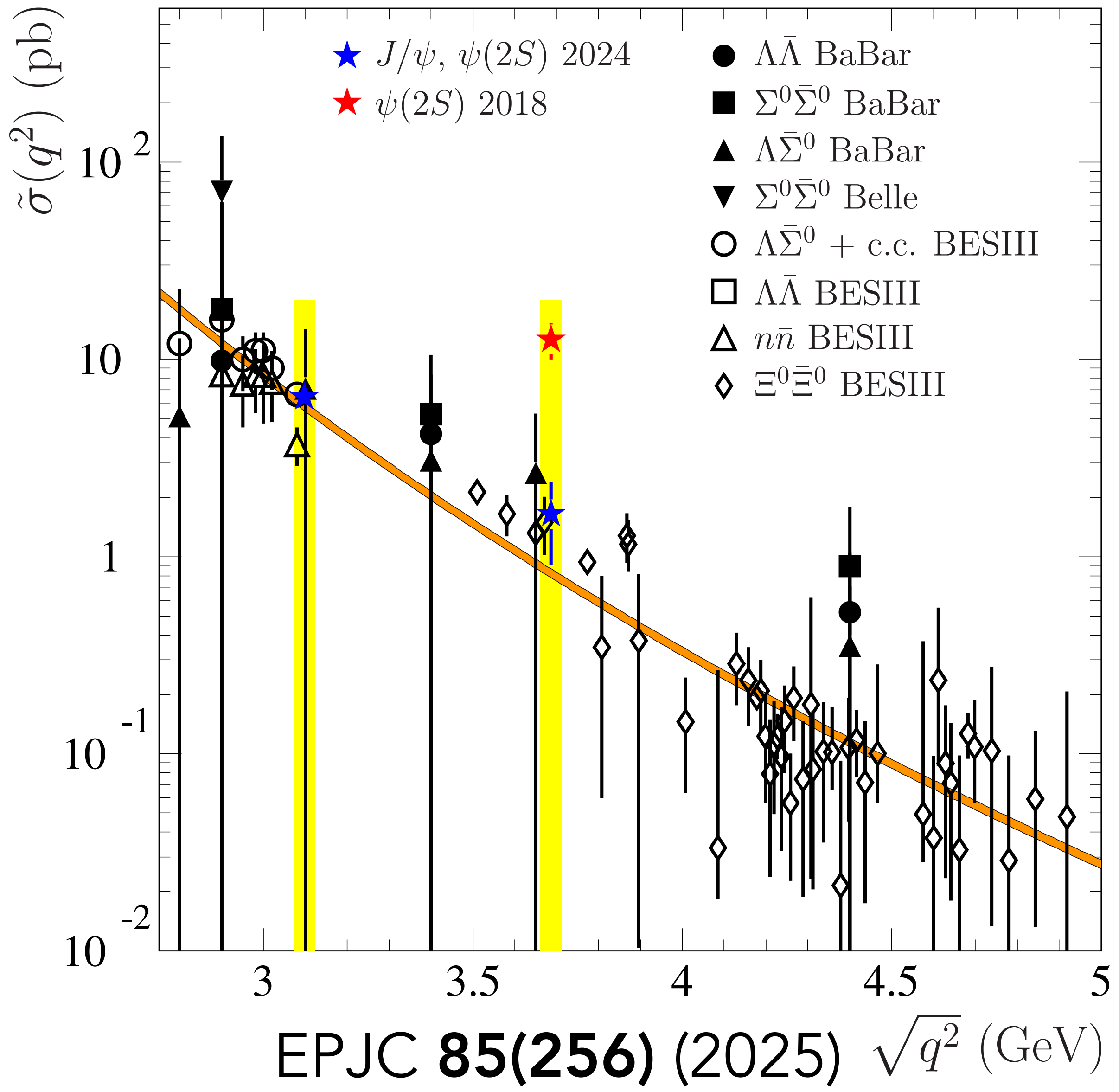
$$\tilde{\sigma}_{\rm fit}(M^2_{J/\psi}) = (5.79 \pm 0.30)\,\mathrm{pb} \qquad \tilde{\sigma}_{\rm fit}(M^2_{\psi(2S)}) = (0.825 \pm 0.043)\,\mathrm{pb}$$

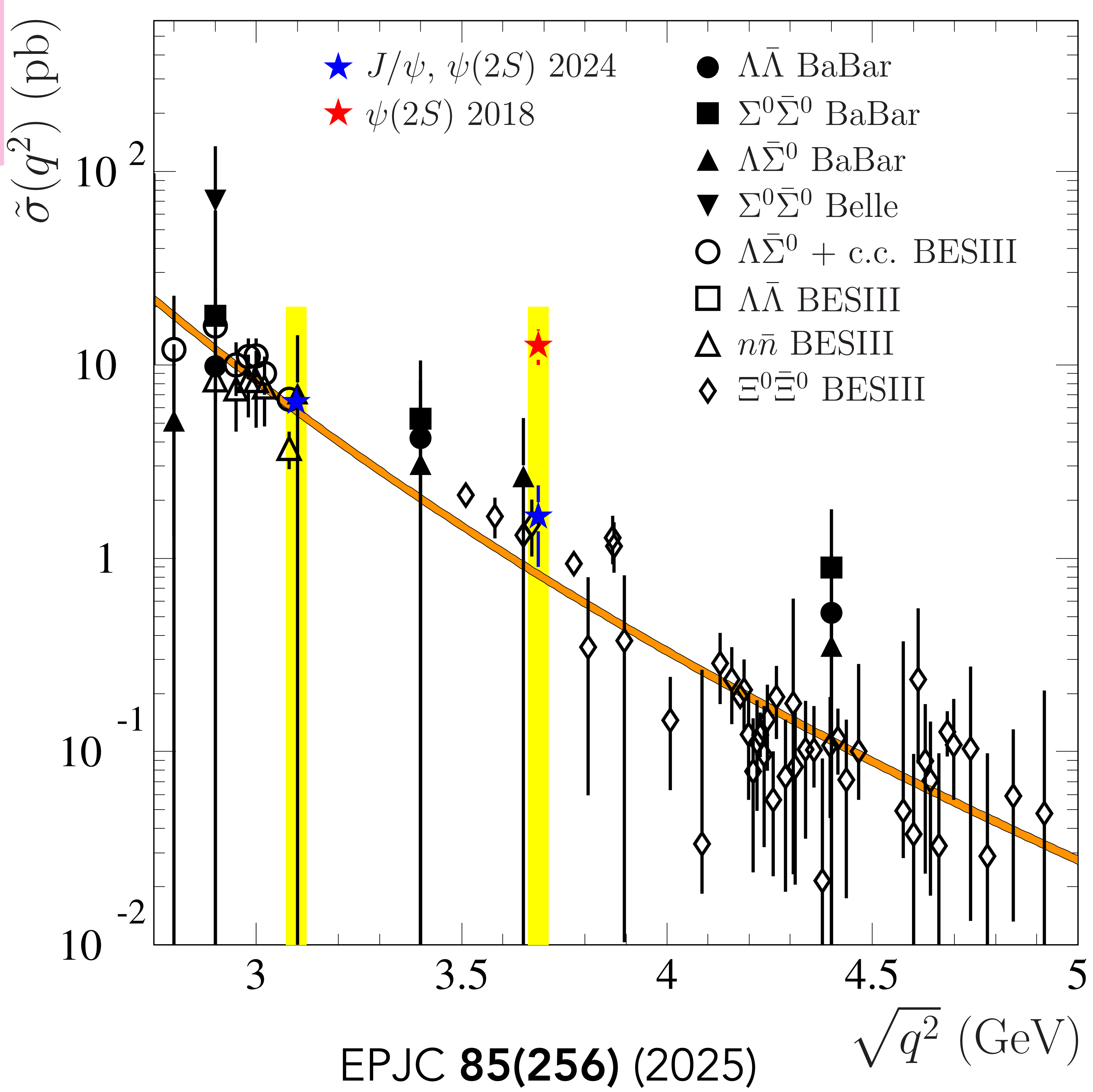


EPJC **85(256)** (2025)

FROM THE THEORY

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

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



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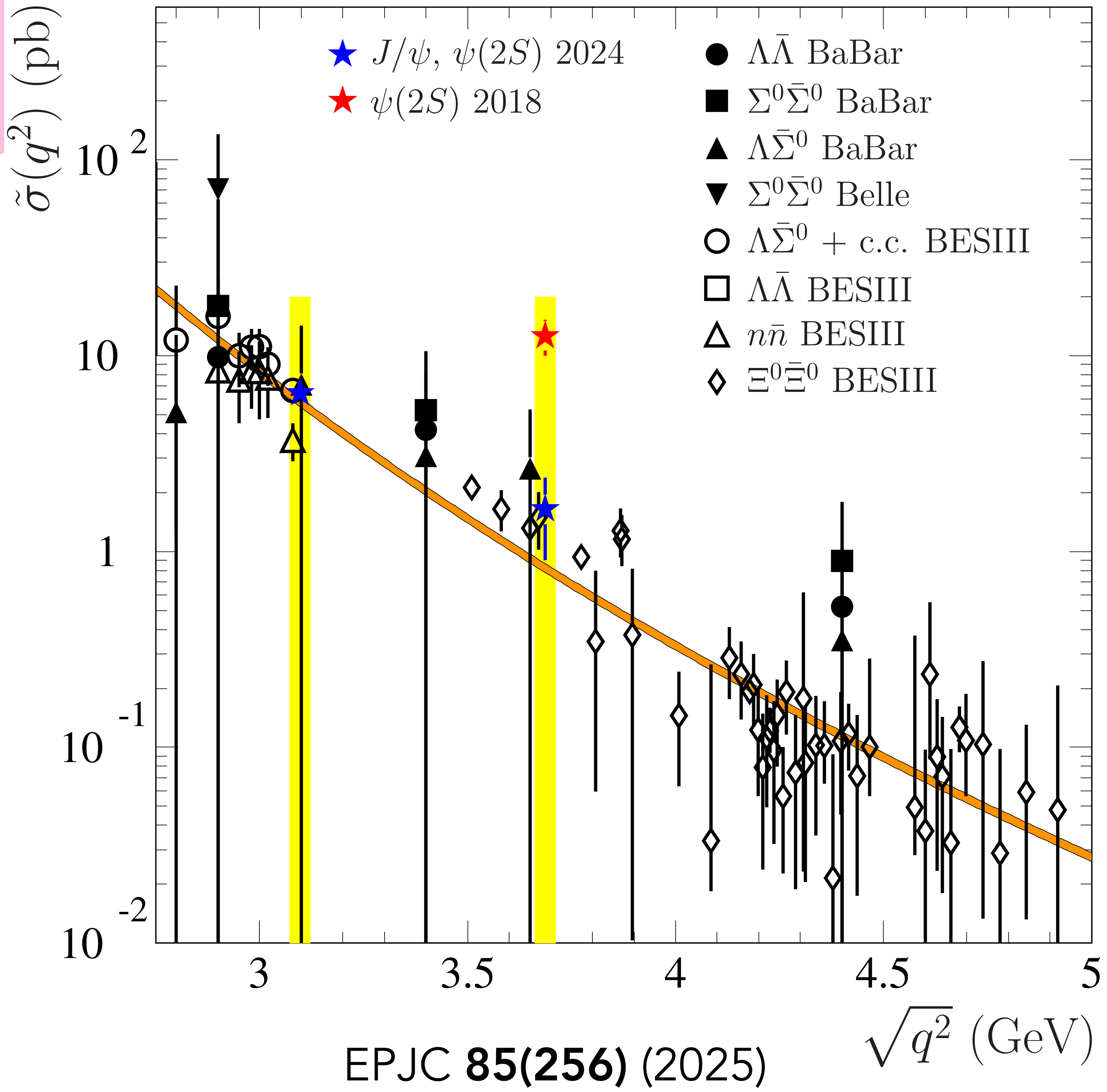
$$\frac{\Gamma^{J/\psi}_{\Lambda\bar{\Sigma}^0}/\Gamma^{J/\psi}_{\mu\mu}}{\Gamma^{\psi(2S)}_{\Lambda\bar{\Sigma}^0}/\Gamma^{\psi(2S)}_{\mu\mu}} = \begin{cases} 0.31 \pm 0.07 & 2018 \\ 2.4 \pm 1.0 & 2024 \end{cases}$$

- 2018 value is less than 1!



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ISOSPIN-VIOLATING EFFECT 1/2

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

$$g_{E,M}^{B_1B_2} = G_{E,M}^{B_1B_2}(M_\psi^2)$$

- 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 $R^\psi_{B_1B_2}$:

$$R^\psi_{B_1B_2} = \left|A^\gamma_{B_1B_2}(M_\psi^2) + A^{I}_{B_1B_2}\right| / \left|A^\gamma_{B_1B_2}(M_\psi^2)\right|$$

Dependance over a relative phase

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

$$g_{E,M}^{B_1B_2} \neq G_{E,M}^{B_1B_2}(M_\psi^2)$$

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

Isospin-violating contribution

$$\Gamma_{B_1B_2}^{\psi} = \beta_{B_1B_2}(M_\psi^2)\Gamma_{\mu\mu}^{\psi}\left|A_{B_1B_2}^{\gamma}(M_\psi^2) + A_{B_1B_2}^{\mathcal{I}}\right|^2$$

- We define the ratio $R_{B_1B_2}^{\psi}$:

$$R_{B_1B_2}^{\psi} = \left|A_{B_1B_2}^{\gamma}(M_\psi^2) + A_{B_1B_2}^{\mathcal{I}}\right| / \left|A_{B_1B_2}^{\gamma}(M_\psi^2)\right|$$

Dependance over a relative phase

Study of $R_{B_1B_2}^{\psi}$ as a function of the relative phase $\phi_{B_1B_2}^{\psi}$!

ISOSPIN-VIOLATING EFFECT 2/2

- $R^{\psi}_{B_1B_2}$ as a function of the relative phase;

$$|A^{\gamma}_{B_1B_2}(M^2_{\psi}) + A^{I}_{B_1B_2}|^2 = |A^{\gamma}_{B_1B_2}(M^2_{\psi})|^2 + |A^{I}_{B_1B_2}|^2 + 2|A^{\gamma}_{B_1B_2}(M^2_{\psi})||A^{I}_{B_1B_2}|\cos\left(\phi^{\psi}_{B_1B_2}\right)$$

$$|A^{I}_{B_1B_2}|/|A^{\gamma}_{B_1B_2}(M^2_{\psi})| = \sqrt{\left(R^{\psi}_{B_1B_2}\right)^2 - \sin^2\left(\phi^{\psi}_{B_1B_2}\right)} - \cos\left(\phi^{\psi}_{B_1B_2}\right)$$

- Values of $R^{\psi}_{B_1B_2}$ extracted from the cross section fit.

ISOSPIN-VIOLATING EFFECT 2/2

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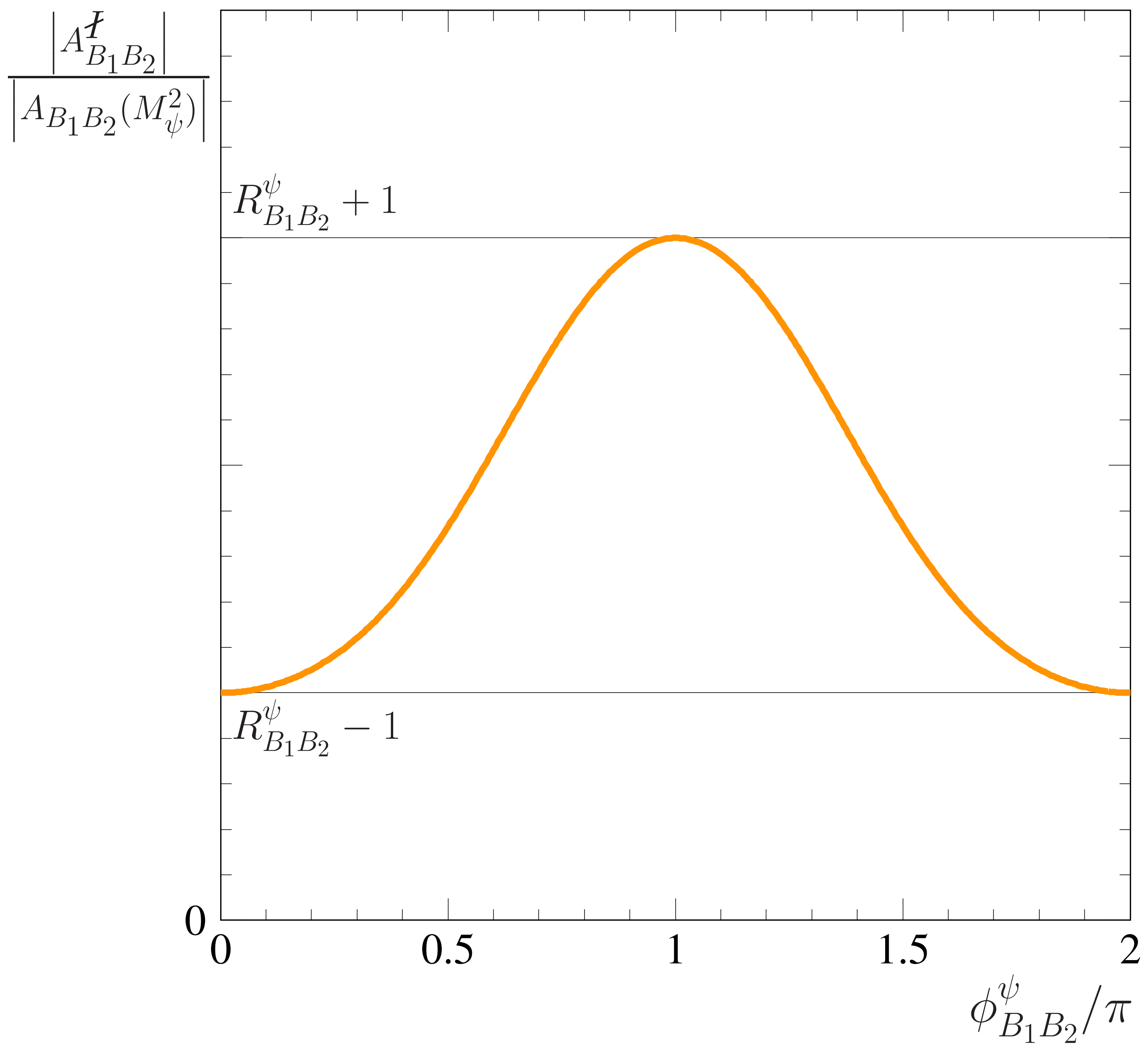

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- Values of $R^{\psi}_{B_1B_2}$ extracted from the cross section fit.

Isospin Strikes Back 1/2

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ISOSPIN STRIKES BACK 1/2

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

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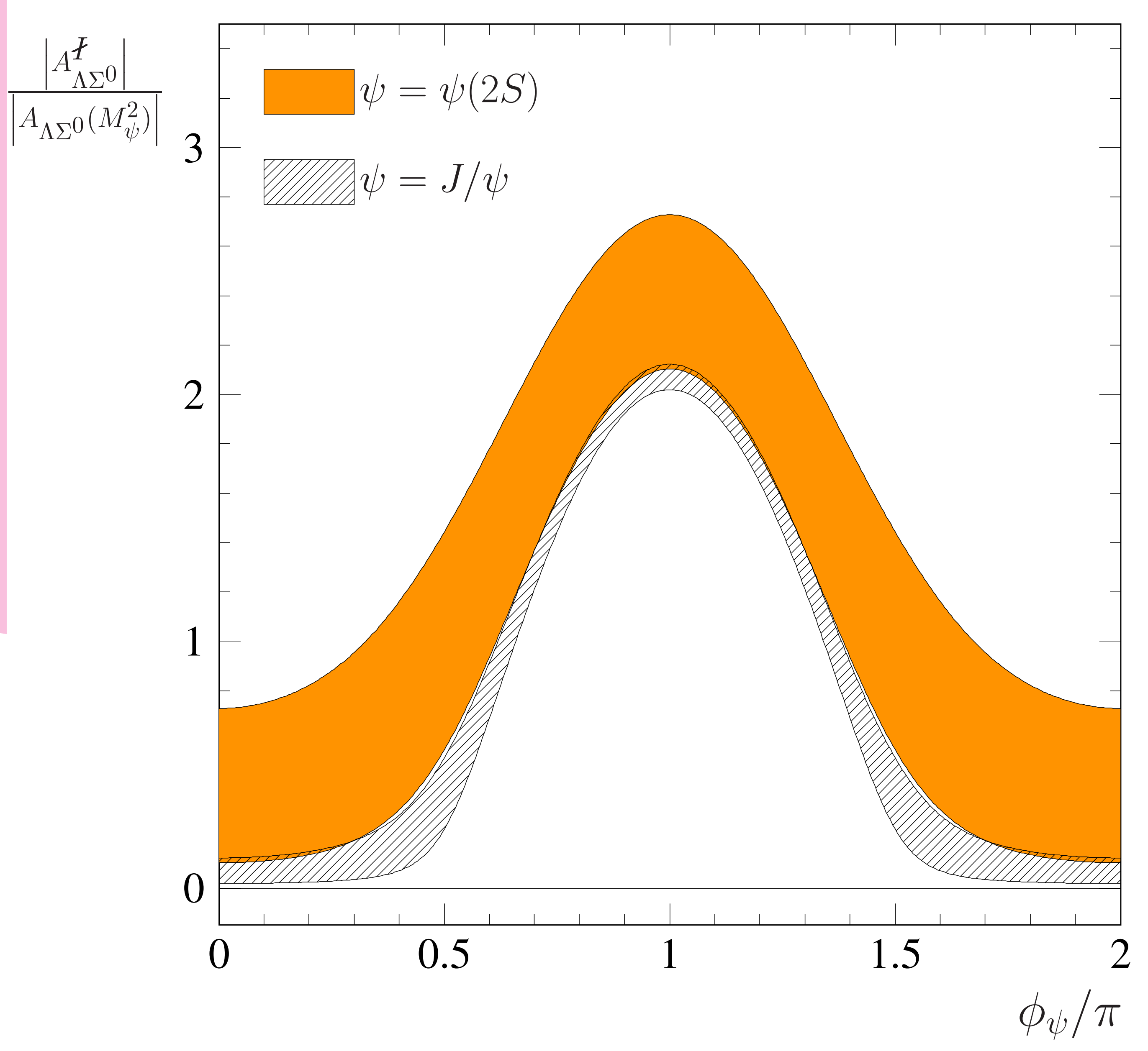

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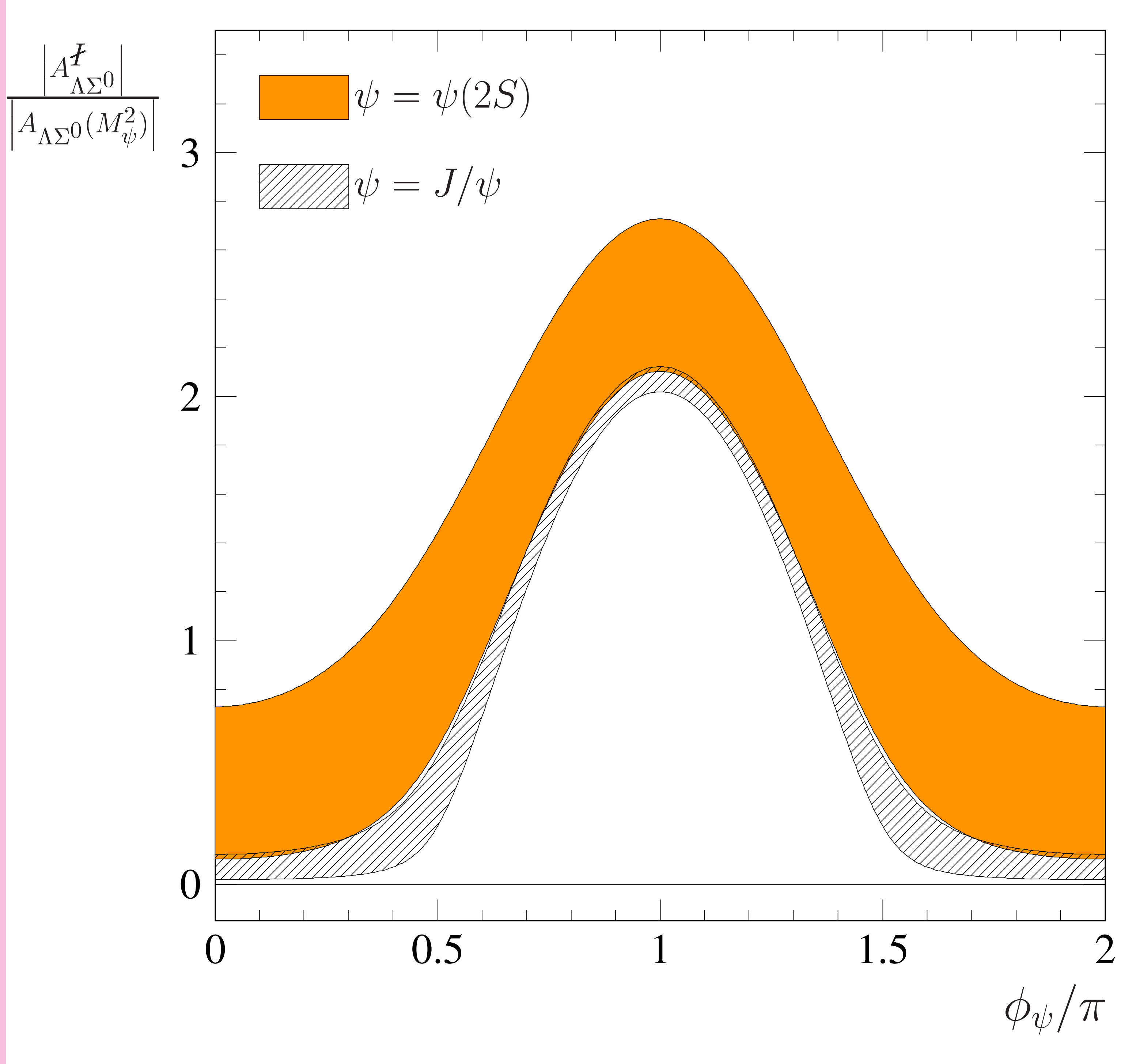
- Minimum = $R^{\psi}_{\Lambda\bar{\Sigma}^0} - 1$ at $\phi^{\psi}_{\Lambda\bar{\Sigma}^0} = \{0, 2\pi\} \Rightarrow$ iso-violating and iso-conserving amplitudes have the same sign;
- Maximum = $R^{\psi}_{\Lambda\bar{\Sigma}^0} + 1$ at $\phi^{\psi}_{\Lambda\bar{\Sigma}^0} = \pi \Rightarrow$ iso-violating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

ISOSPIN STRIKES BACK 2/2

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



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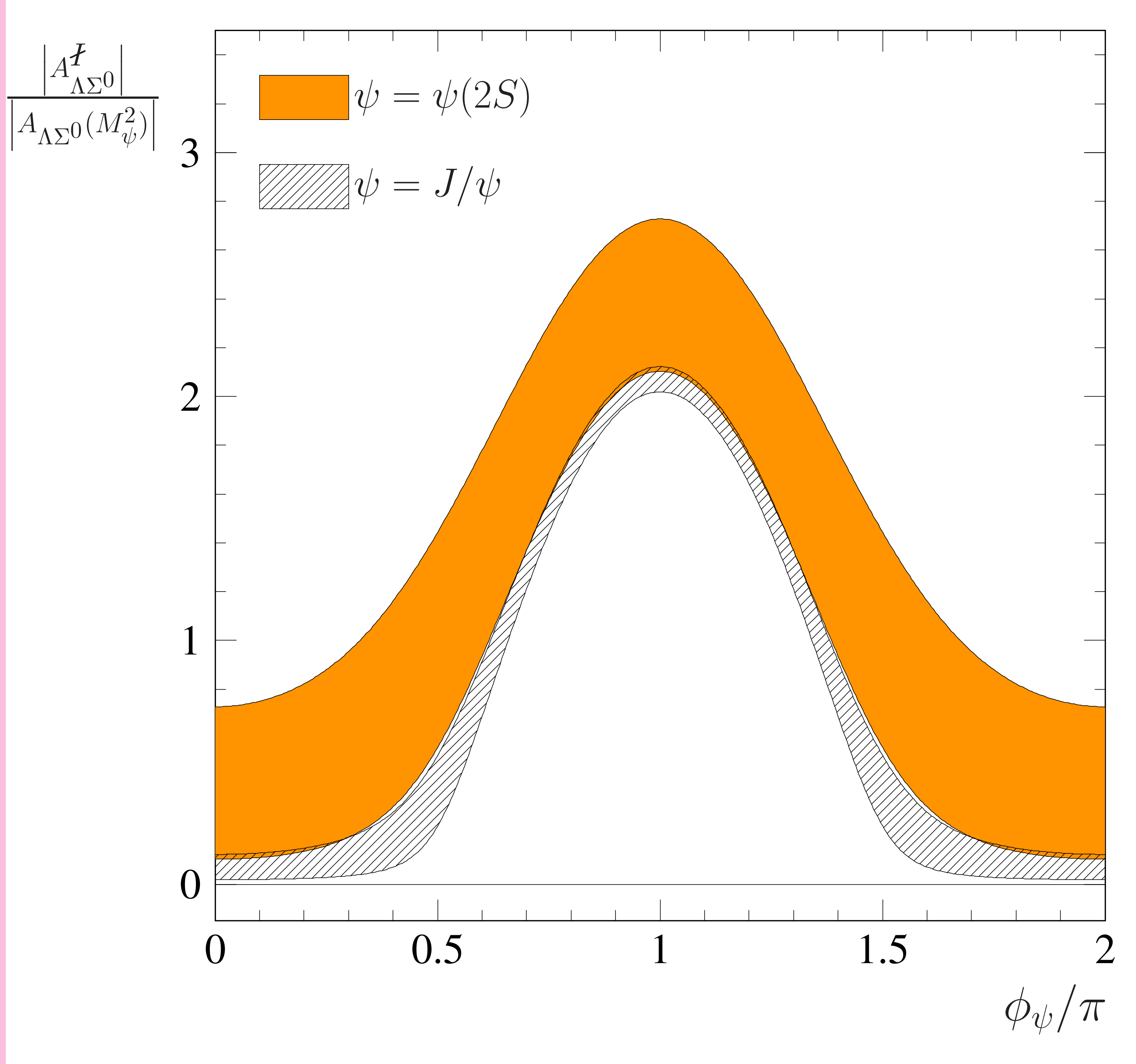

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$$\left.\frac{|A^{\not I}_{\Lambda\bar{\Sigma}^0}|}{|A^{\gamma}_{\Lambda\bar{\Sigma}^0}(M^2_{\psi(2S)})|}\right|_{\phi^{\psi(2S)}_{\Lambda\bar{\Sigma}^0}=0} = R^{\psi(2S)}_{\Lambda\bar{\Sigma}^0} - 1 = 0.41 \pm 0.31$$

$$\left.\frac{|A^{\not I}_{\Lambda\bar{\Sigma}^0}|}{|A^{\gamma}_{\Lambda\bar{\Sigma}^0}(M^2_{J/\psi})|}\right|_{\phi^{J/\psi}_{\Lambda\bar{\Sigma}^0}=0} = R^{J/\psi}_{\Lambda\bar{\Sigma}^0} - 1 = 0.07 \pm 0.06$$

Both results comparable with zero!

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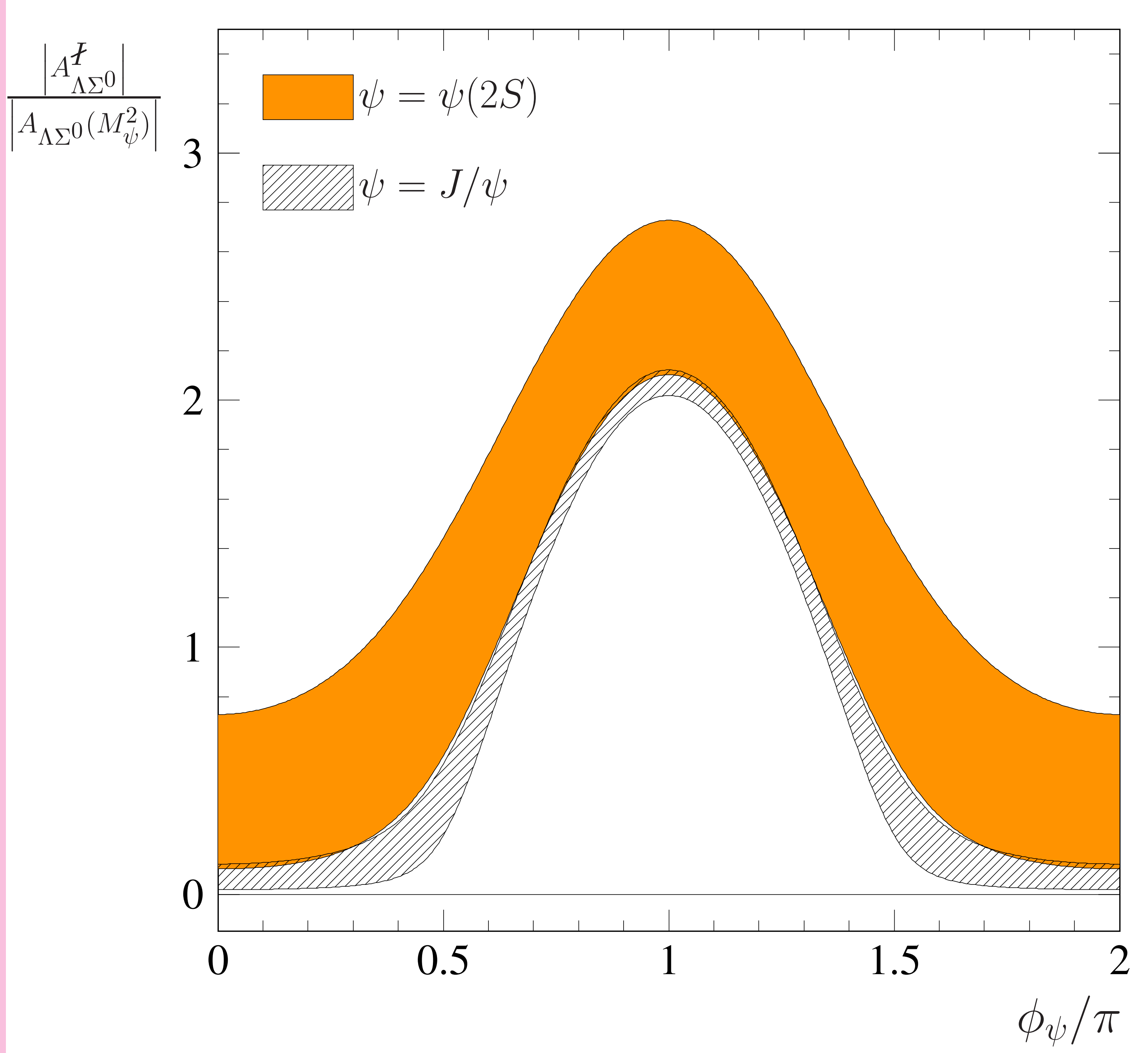

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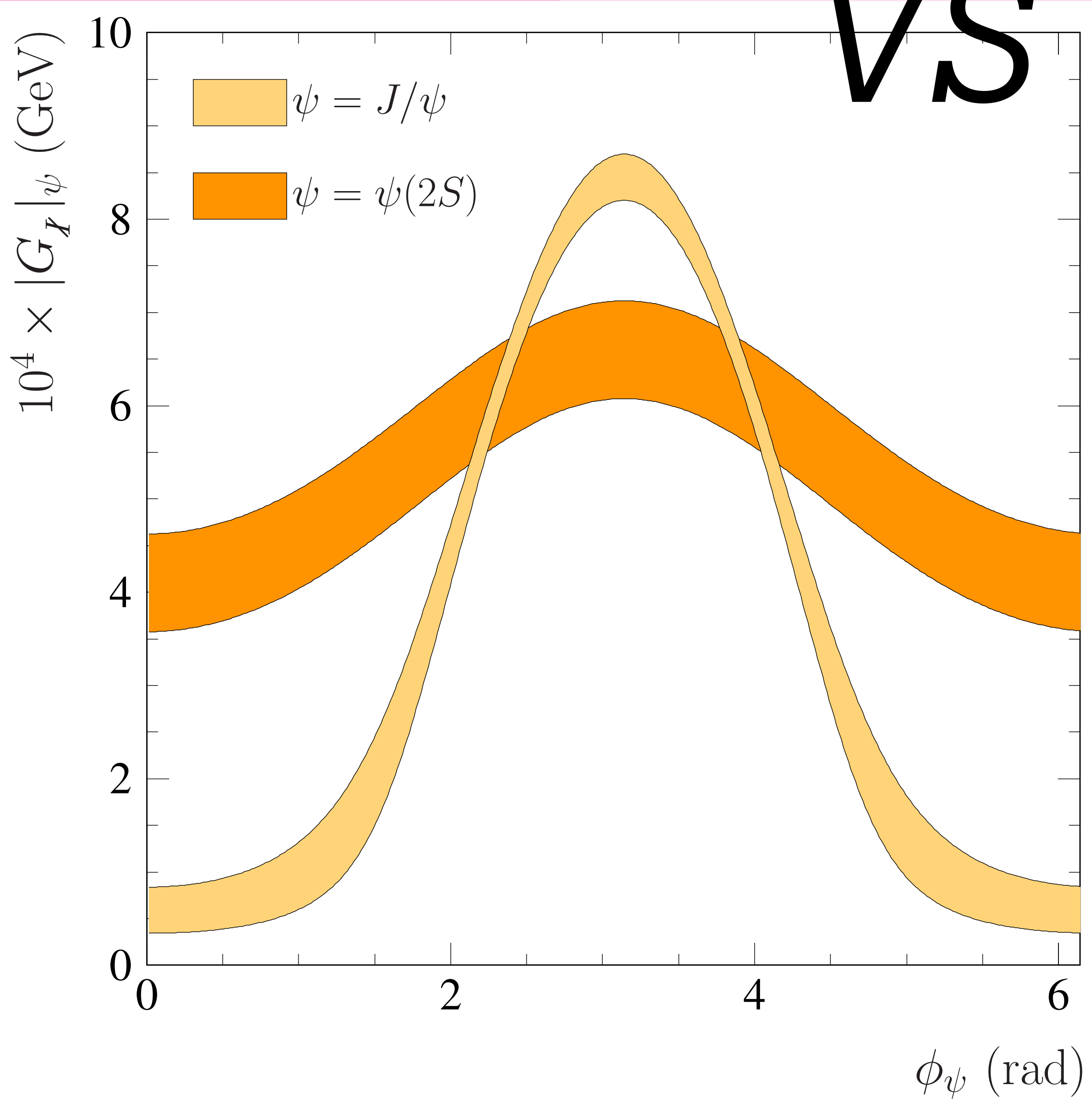

EPJC **80(9)** (2020)

SUMMARY

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

SUMMARY

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THANKS FOR YOUR ATTENTION