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Southern Center for Nuclear-Science Theory

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中国科学院大学
University of Chinese Academy of Sciences

Hyperon Time-like Electromagnetic Form Factors in Vector Meson Dominance model

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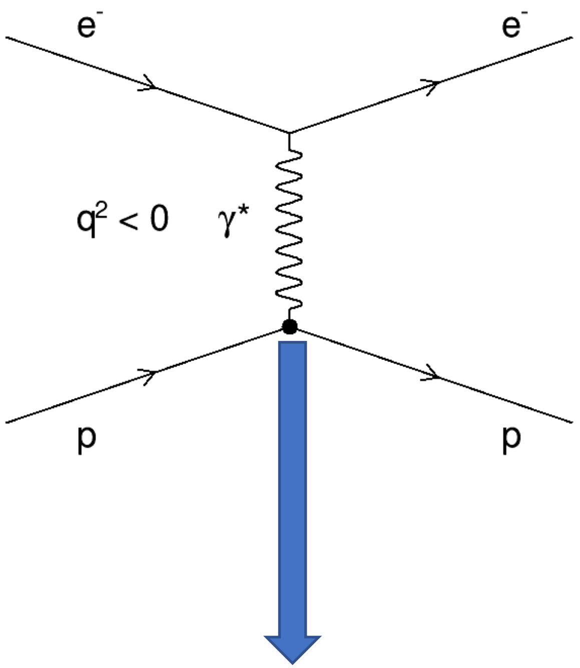
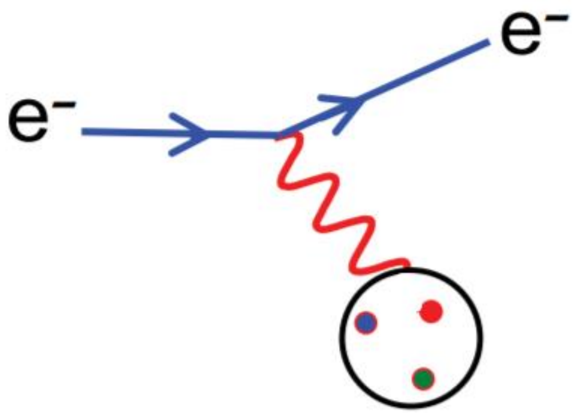
Cairns, Queensland, Australia

Outline

- Introduction：Electromagnetic Form Factors
- The model: Vector Meson Dominance
- Hyperon electromagnetic form factors
- Summary

Electromagnetic form factors (space-like)





$$\langle p_f | \hat{J}^\mu(0) | p_i \rangle = \overline{u}(p_f) \left[F_1(q^2)\gamma^\mu - F_2(q^2)\frac{\sigma^{\mu\nu} q_\nu}{2M} \right] u(p_i)$$

$$\Gamma^\mu(q^2) = \gamma^\mu F_1^p(q^2) + i\frac{F_2^p(q^2)}{2M_p}\sigma^{\mu\nu}q_\nu$$

F_1^N : Dirac form factor

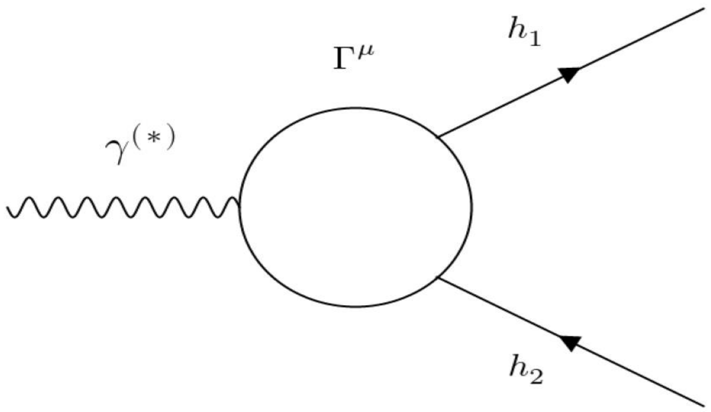
F_2^N: Pauli form factor

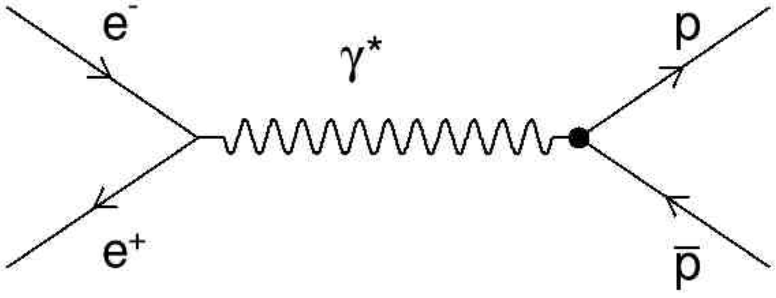
$$G_E^N(Q^2) = F_1^N(Q^2) - \tau F_2^N(Q^2)\ ,\ \ G_M^N(Q^2) = F_1^N(Q^2) + F_2^N(Q^2)\ ,\ \ \tau = \frac{Q^2}{4M_N^2}$$

$$F_1^p(0) = 1\ ,\ F_1^n(0) = 0\ ,\ \ F_2^p(0) = \kappa_p\ ,\ F_2^n(0) = \kappa_n$$

S. Pacetti, R. Baldini Ferroli and E. Tomasi-Gustafsson, “Proton electromagnetic form factors: Basic notions, present achievements and future perspectives,” **Phys. Rept. 550-551, 1-103 (2015).**

Electromagnetic form factors (time-like)

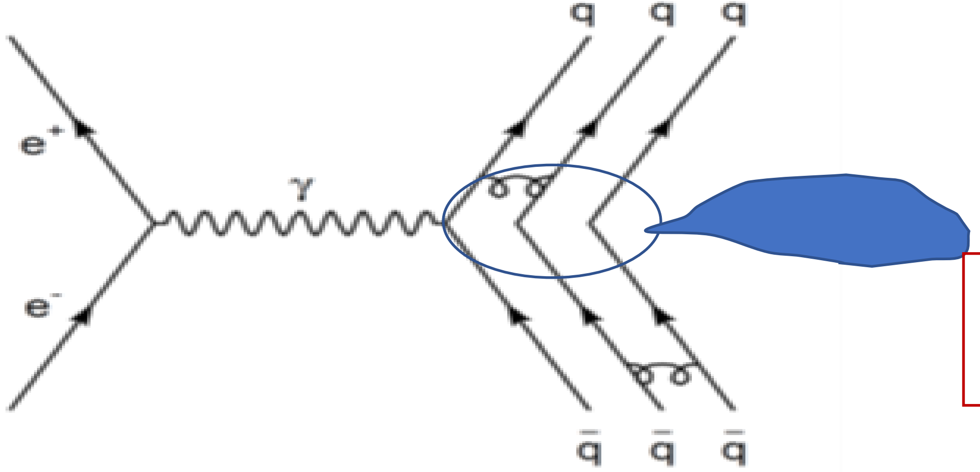




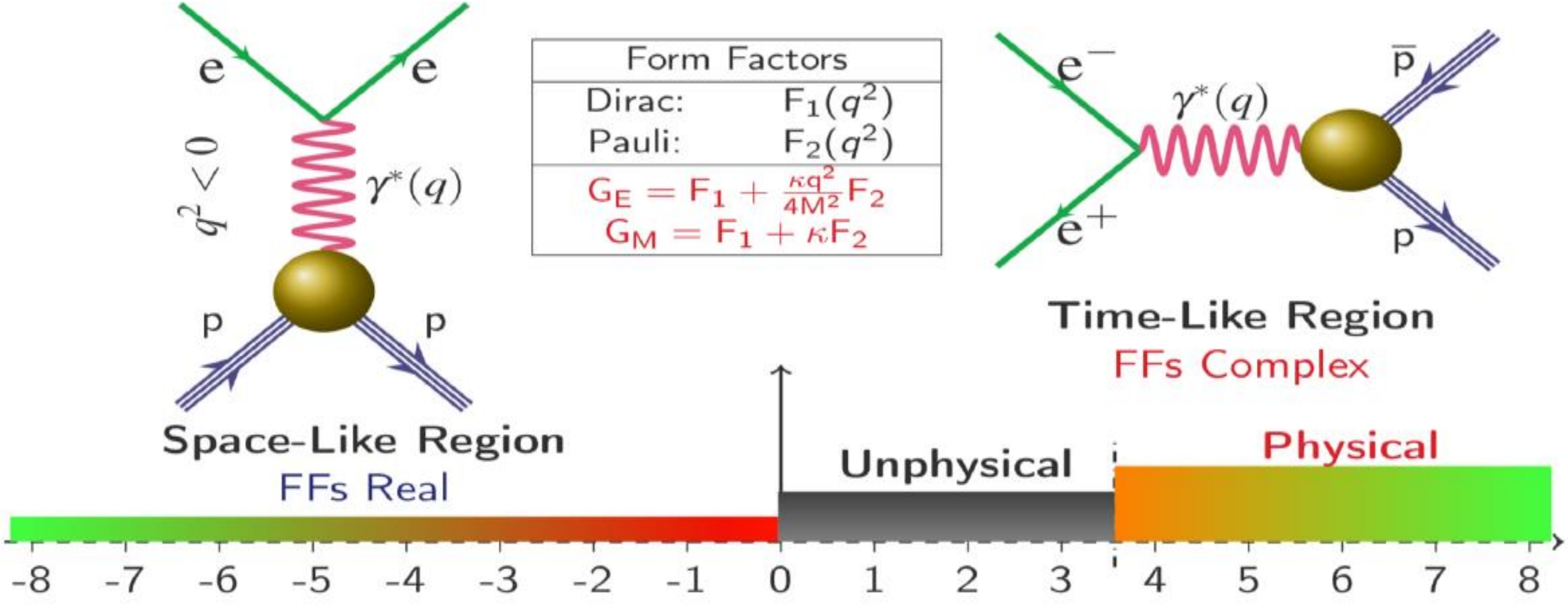
$$\left(\frac{d\sigma}{d\Omega}\right)^{th}_{e^+e^-\to N\bar{N}} = \frac{\alpha^2\beta}{4q^2} C_N(q^2)\left\{|G_M^N(q^2)|^2(1+\cos^2\theta) + |G_E^N(q^2)|^2\frac{1}{\tau}\sin^2\theta\right\}$$

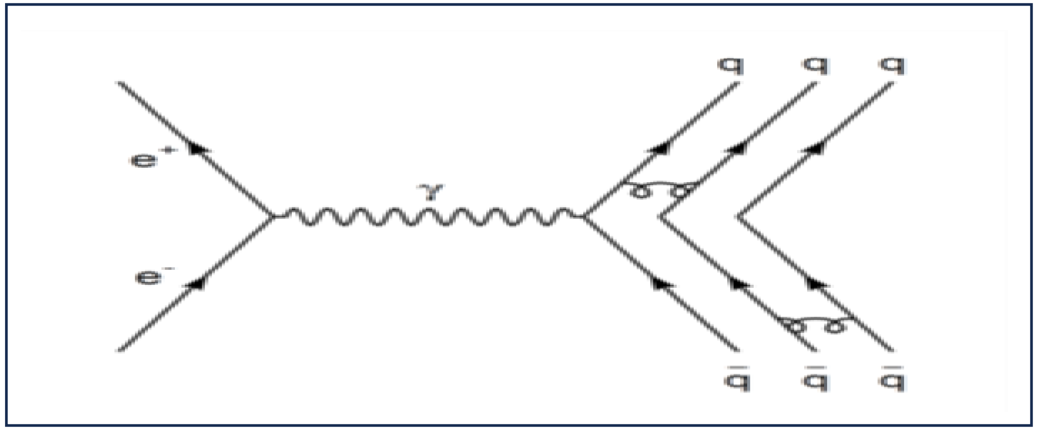
$$\sigma^{th}_{e^+e^-\to N\bar{N}} = \frac{\alpha^2\beta}{4q^2} C_N(q^2)\int d\Omega\left[|G_M^N(q^2)|^2(1+\cos^2\theta) + |G_E^N(q^2)|^2\frac{\sin^2\theta}{\tau}\right]$$

$$= \frac{4\pi\alpha^2\beta}{3q^2} C_N(q^2)\left[|G_M^N(q^2)|^2 + \frac{|G_E^N(q^2)|^2}{2\tau}\right].$$



$$|G_{eff}(q^2)| = \sqrt{\frac{\sigma(q^2)}{\sigma_{point}(q^2)}} = \sqrt{\frac{|G_M(s)|^2 + \frac{2M^2}{s}|G_E(s)|^2}{1+\frac{2M^2}{s}}}$$

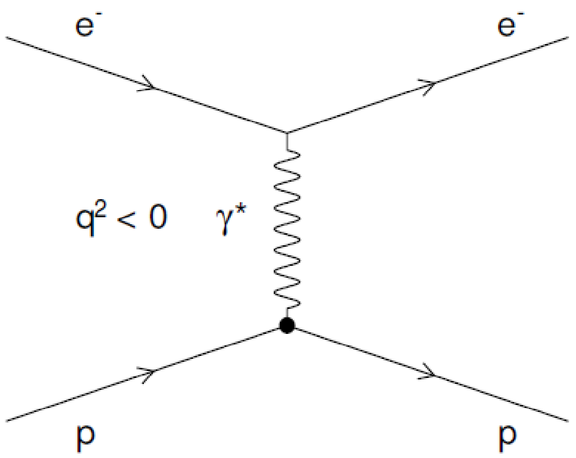


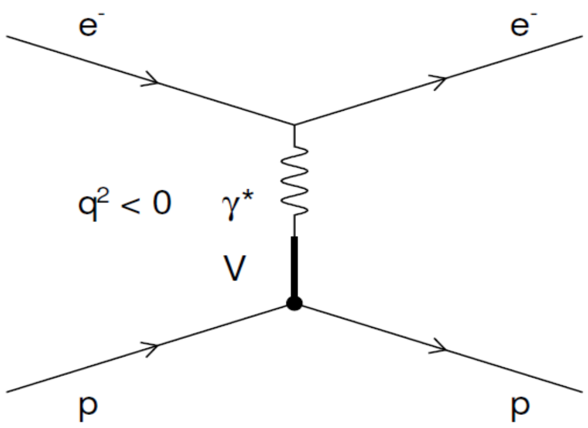


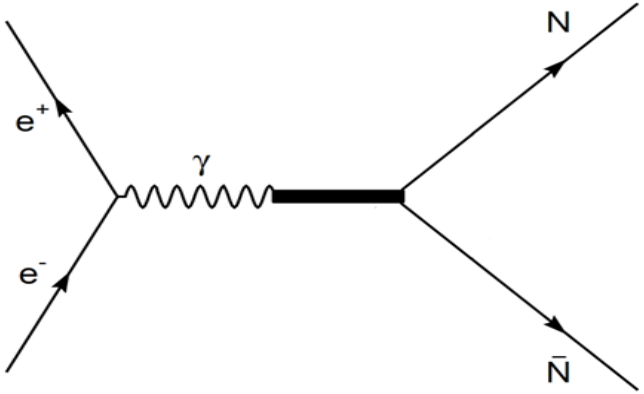
From QED to QCD

Both QED and QCD

VMD: vector meson dominance model







Dirac and Pauli isoscalar and isovector form factors are

$$F_1^S(t) = \frac{e}{2} g(t) \left[(1 - \beta_\omega - \beta_\phi) + \beta_\omega \frac{\mu_\omega^2}{\mu_\omega^2 - t} + \beta_\phi \frac{\mu_\phi^2}{\mu_\phi^2 - t} \right]$$

$$F_1^V(t) = \frac{e}{2} g(t) \left[(1 - \beta_\rho) + \beta_\rho \frac{\mu_\rho^2}{\mu_\rho^2 - t} \right]$$

$$F_2^S(t) = \frac{e}{2} g(t) \left[(-0.120 - \alpha_\phi) \frac{\mu_\omega^2}{\mu_\omega^2 - t} + \alpha_\phi \frac{\mu_\phi^2}{\mu_\phi^2 - t} \right]$$

$$F_2^V(t) = \frac{e}{2} g(t) \left[3.706 \frac{\mu_\rho^2}{\mu_\rho^2 - t} \right]$$

$$F_1 = F_1^S + F_1^V$$

$$F_2 = F_2^S + F_2^V$$

$$G_E = F_1 - \tau F_2$$

$$G_M = F_1 + F_2$$

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SEMI-PHENOMENOLOGICAL FITS TO NUCLEON ELECTROMAGNETIC FORM FACTORS

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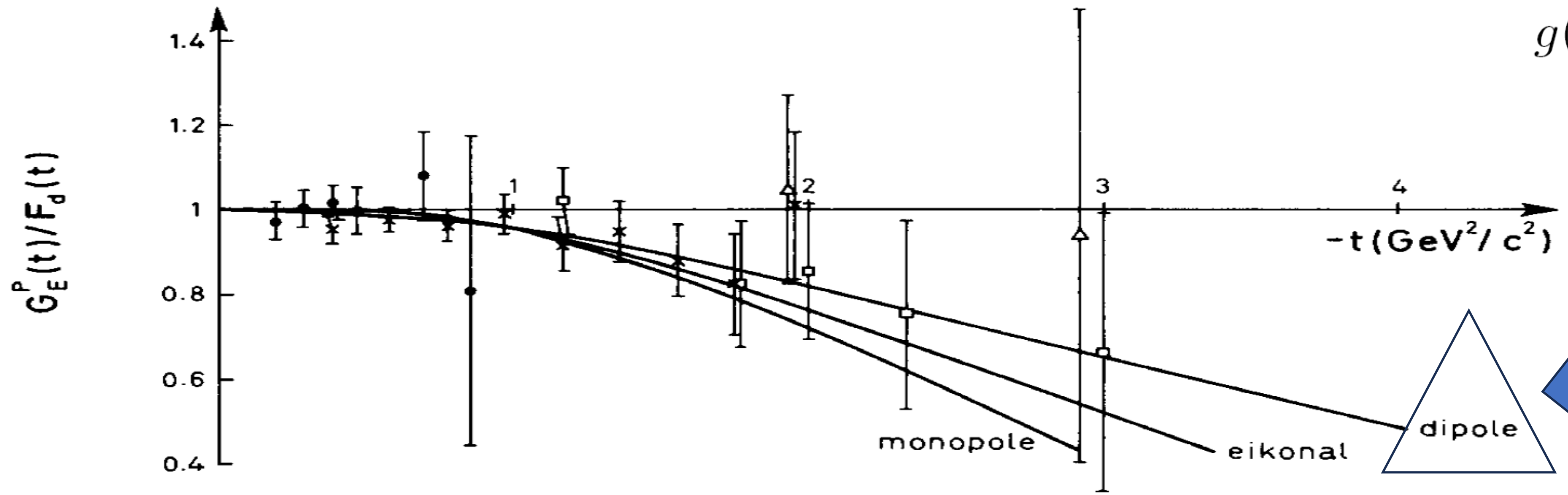
Institute for Theoretical Physics, University of Groningen, Groningen, The Netherlands

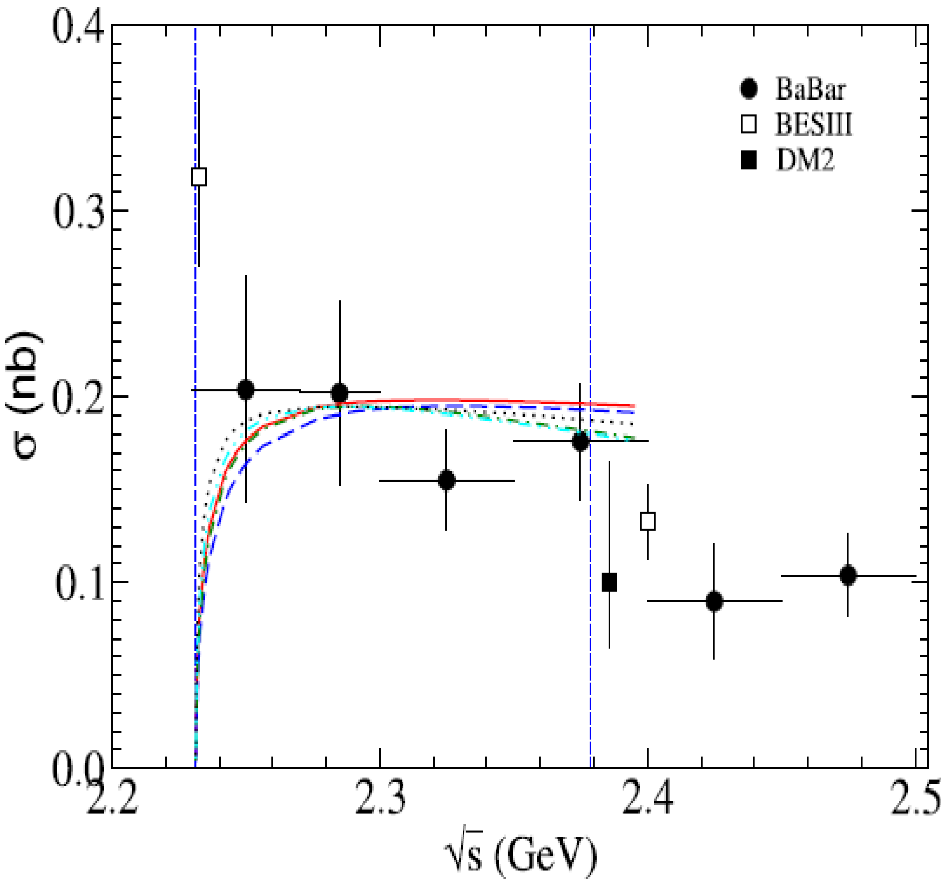
Received 31 August 1972

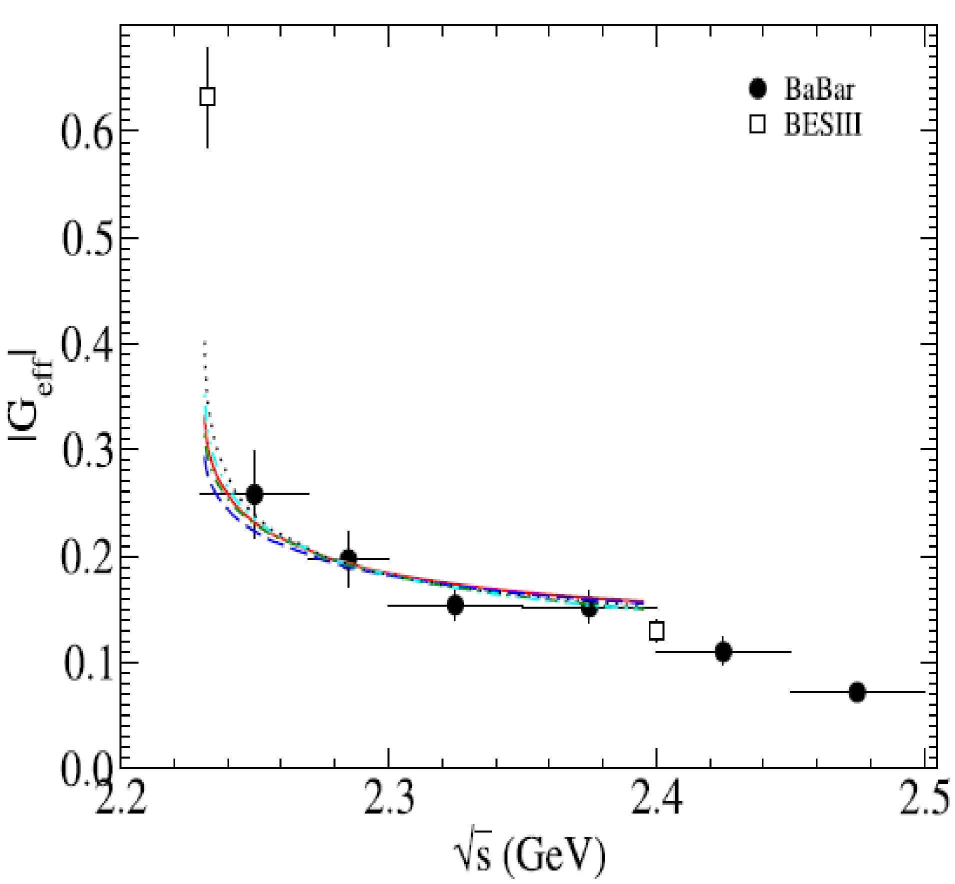
Several theoretically interesting forms of the nucleon EM form factor have been considered and found to provide quantitative descriptions of available data with as few as three adjustable parameters.



$$g(q^2) = \frac{1}{(1-\gamma q^2)^2}$$

Λ





J. Haidenbauer and U. G. Meißner, Phys. Lett. B 761, 456-461(2016).

EMFFs of Λ in the VMD

$$F_1(Q^2) = g(Q^2)[-\beta_\omega - \beta_\phi + \beta_\omega \frac{m_\omega^2}{m_\omega^2 + Q^2} + \beta_\phi \frac{m_\phi^2}{m_\phi^2 + Q^2} + \beta_x \frac{m_x^2}{m_x^2 + Q^2}]$$

$$F_2(Q^2) = g(Q^2)[(\mu_\Lambda - \alpha_\phi) \frac{m_\omega^2}{m_\omega^2 + Q^2} + \alpha_\phi \frac{m_\phi^2}{m_\phi^2 + Q^2} + \alpha_x \frac{m_x^2}{m_x^2 + Q^2}]$$

$$g(Q^2) = 1/(1 + \gamma Q^2)^2$$

$$Q^2 \to -q^2$$

$$G_E(q^2) = F_1(q^2) + \tau F_2(q^2)$$
$$G_M(q^2) = F_1(q^2) + F_2(q^2)$$

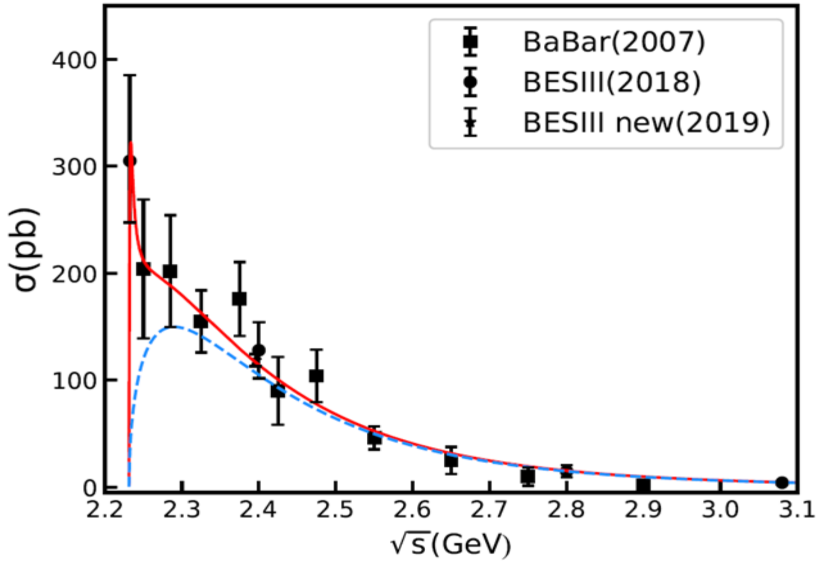
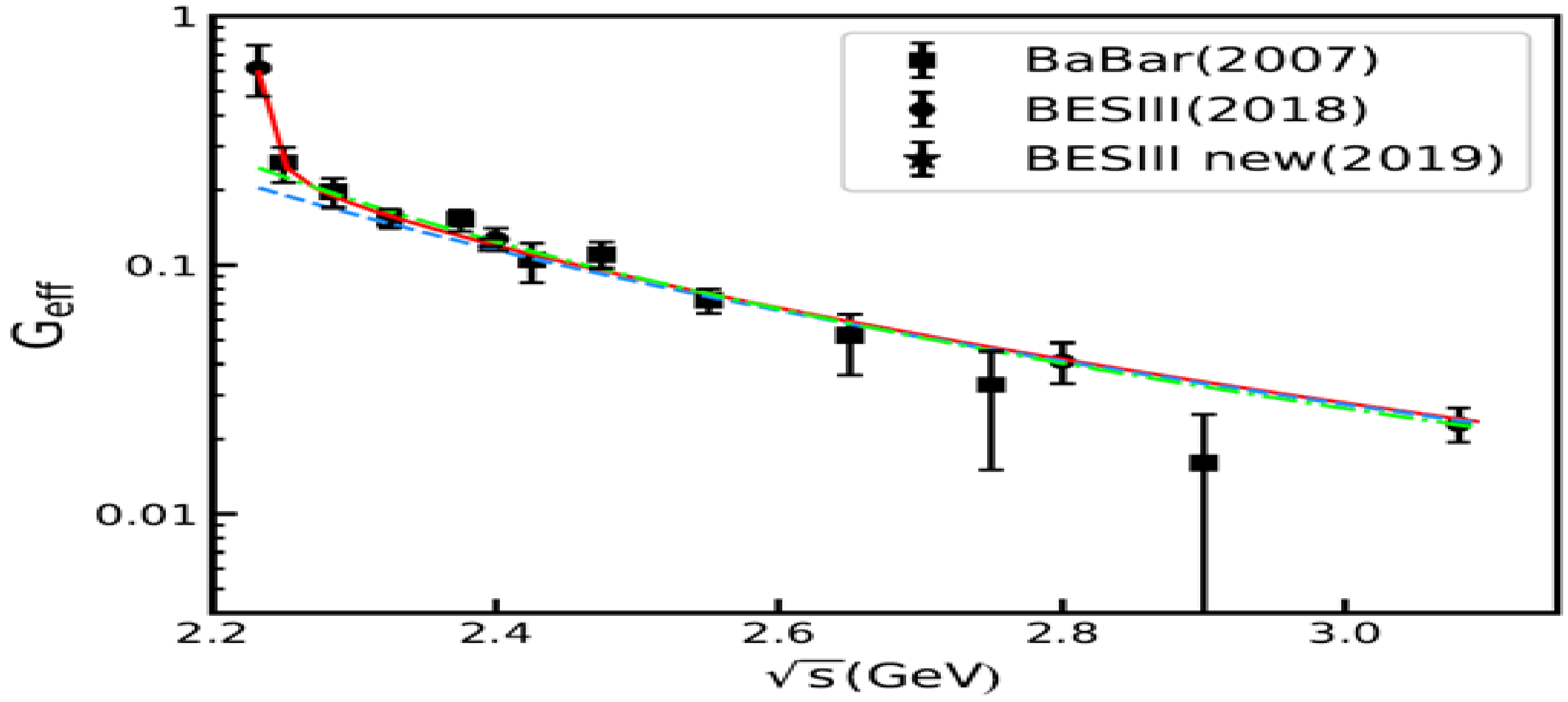


Figure: Cross section of the reaction $e^+e^- \to \bar{\Lambda}\Lambda$.

Z. Y. Li, A. X. Dai and J. J. Xie, Chin. Phys. Lett. 39, 011201 (2022).



Blue: without X(2231)
Red: with X(2231)
Green: only dipole

$$G_{\text{eff}} = C_0 g(q^2) = \frac{C_0}{(1-\gamma q^2)^2}$$

Table: Values of model parameters determined in this work.

Parameter	Value	Parameter	Value
γ (GeV^{-2})	0.43	β_ω	-1.13
β_ϕ	1.35	α_ϕ	-0.40
β_x	0.0015	m_x (MeV)	2230.9
Γ_x(MeV)	4.7		

New state X(2231) ?

Z. Y. Li, A. X. Dai and J. J. Xie, Chin. Phys. Lett. 39, 011201 (2022).

Flatté formula for the X(2231)

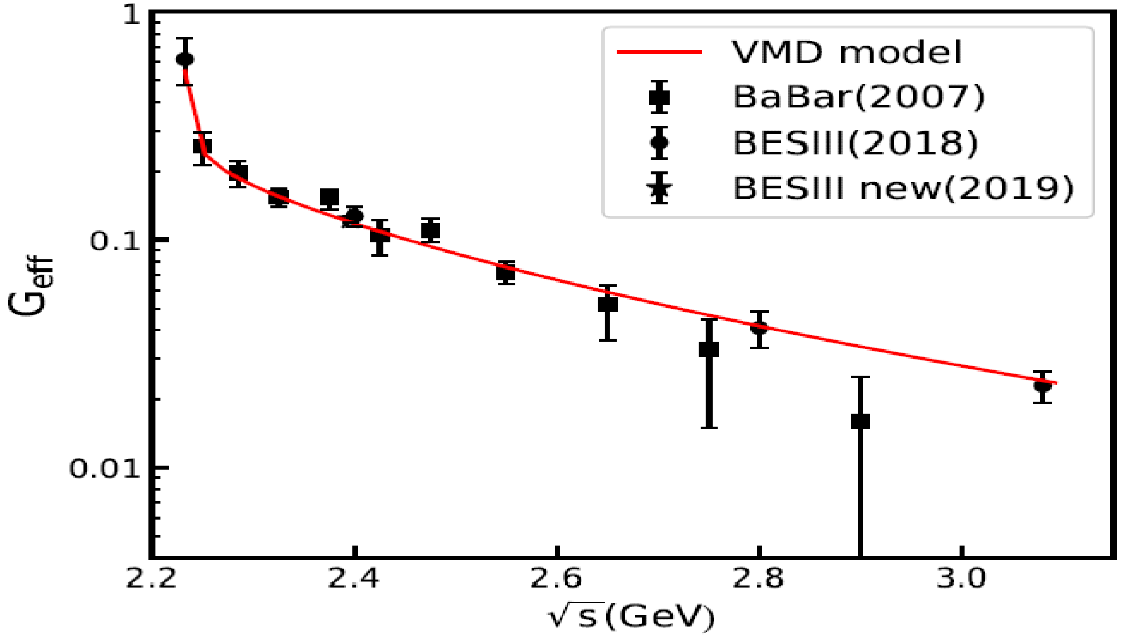


Figure: Fitting result of $|G_{eff}|$ with Flatte.

S.M. Flatte, Phys. Lett. B 63, 224-227 (1976).

$$\frac{d\sigma_i}{dm} = C \left| \frac{m_R\sqrt{\Gamma_0\Gamma_i}}{m_R^2 - m^2 - i m_R(\Gamma_{\pi\eta} + \Gamma_{K\bar{K}})} \right|^2$$

$$\Gamma_{\pi\eta} = g_\eta q_\eta$$

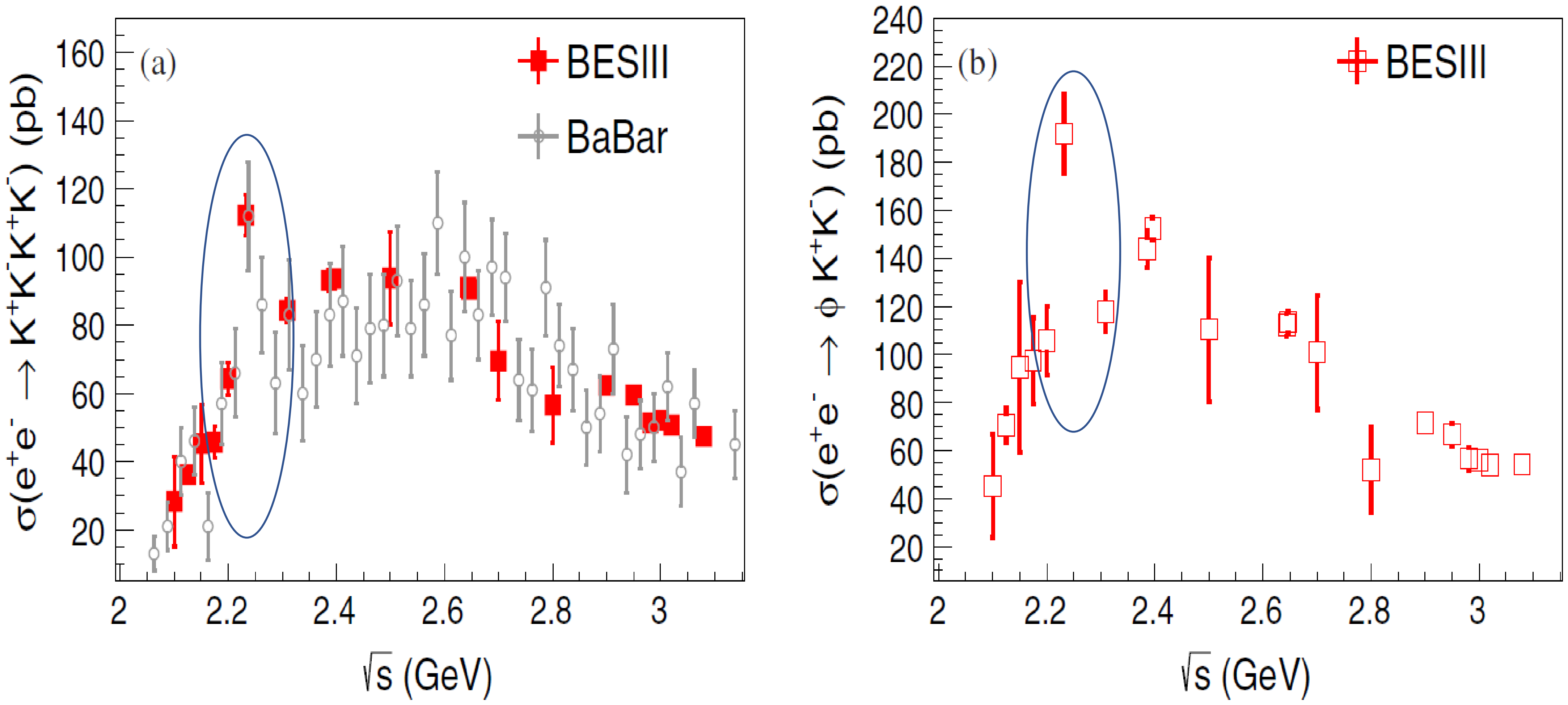
$$\Gamma_{K\bar{K}} = \begin{cases} g_K\sqrt{(1/4)m^2 - m_K^2} & \text{above threshold} \\ i g_K\sqrt{m_K^2 - (1/4)m^2} & \text{below threshold} \end{cases}$$

Parameter	Value	Parameter	Value
γ (GeV^{-2})	0.57 ± 0.21	$\beta_{\omega\phi}$	-0.3 ± 0.31
β_x	-0.03 ± 0.09	m_x(MeV)	2237.7 ± 50.2
Γ_0 (MeV)	$8.8^{+75.9}_{-8.8}$	$g_{\Lambda\bar{\Lambda}}$	3.0 ± 1.9

$$\Gamma_x = \Gamma_0 + \Gamma_{\Lambda\bar{\Lambda}}(s) \qquad \Gamma_{\Lambda\bar{\Lambda}} = \frac{g^2}{4\pi}\sqrt{\frac{s}{4} - M_\Lambda^2}$$

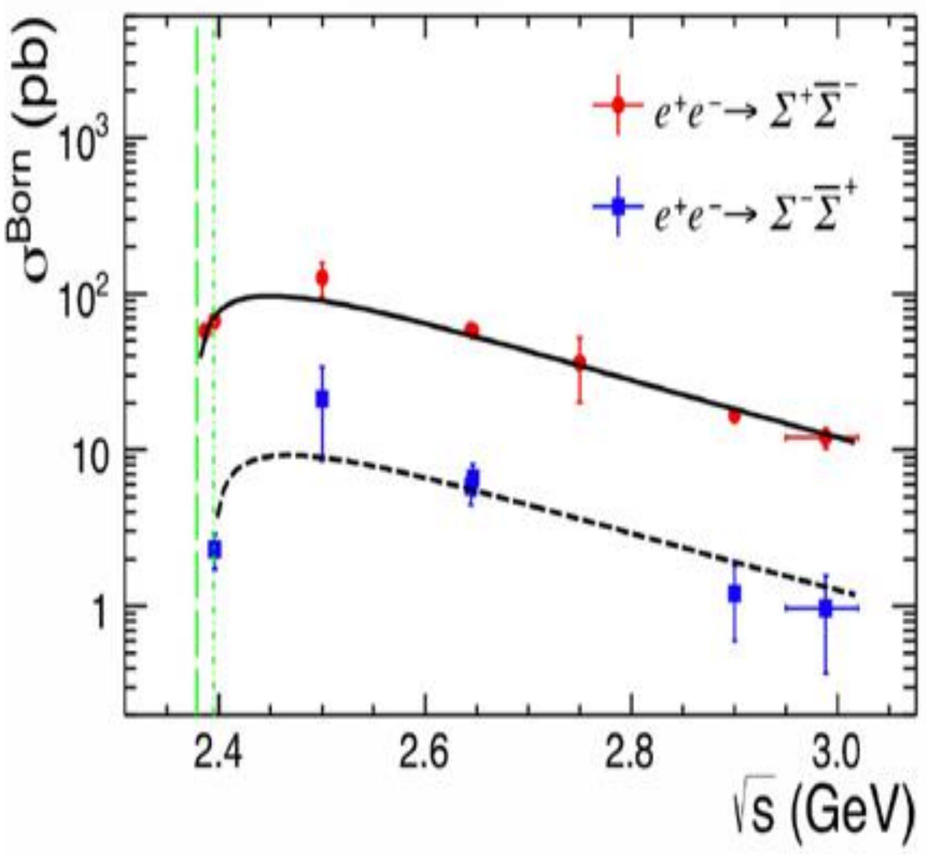
Z. Y. Li, A. X. Dai and J. J. Xie, Chin. Phys. Lett. 39, 011201 (2022).

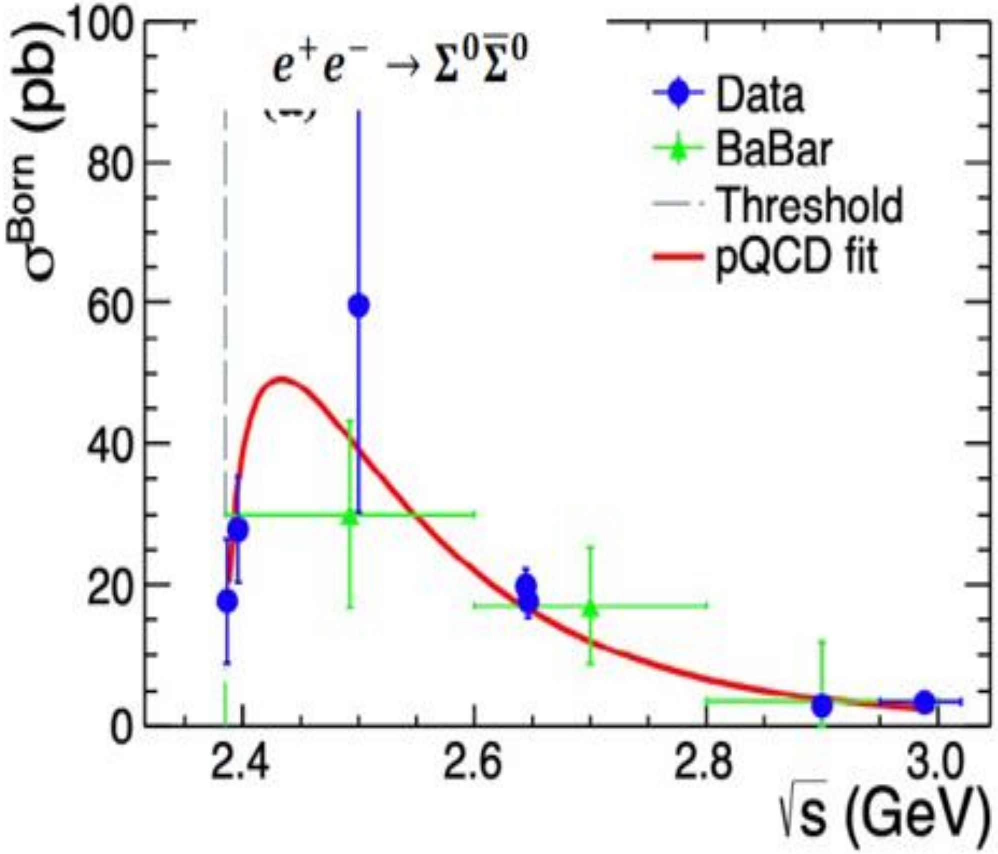
Where is the X(2231)?



M. Ablikim, et al., Phys. Rev. D 100, 032009(2019).

Σ





The ratio $\Sigma^+\bar{\Sigma}^- : \Sigma^0\bar{\Sigma}^0 : \Sigma^-\bar{\Sigma}^+$ is about $9.7 \pm 1.3 : 3.3 \pm 0.7 : 1$.

BESIII, **Phys. Lett. B 814, 136110 (2021) ; Phys. Lett. B 831, 137187 (2022).**

EMFFs of Σ^+, Σ^-, and Σ^0 baryons (VMD)

$$
\begin{aligned}
|\Sigma^+\bar{\Sigma}^-\rangle &= \frac{1}{\sqrt{2}}|1,0\rangle + \frac{1}{\sqrt{3}}|0,0\rangle + \frac{1}{\sqrt{6}}|2,0\rangle \\
|\Sigma^-\bar{\Sigma}^+\rangle &= -\frac{1}{\sqrt{2}}|1,0\rangle + \frac{1}{\sqrt{3}}|0,0\rangle + \frac{1}{\sqrt{6}}|2,0\rangle \\
|\Sigma^0\bar{\Sigma}^0\rangle &= -\frac{1}{\sqrt{3}}|0,0\rangle + \sqrt{\frac{2}{3}}|2,0\rangle
\end{aligned}
$$

Isospin decomposition

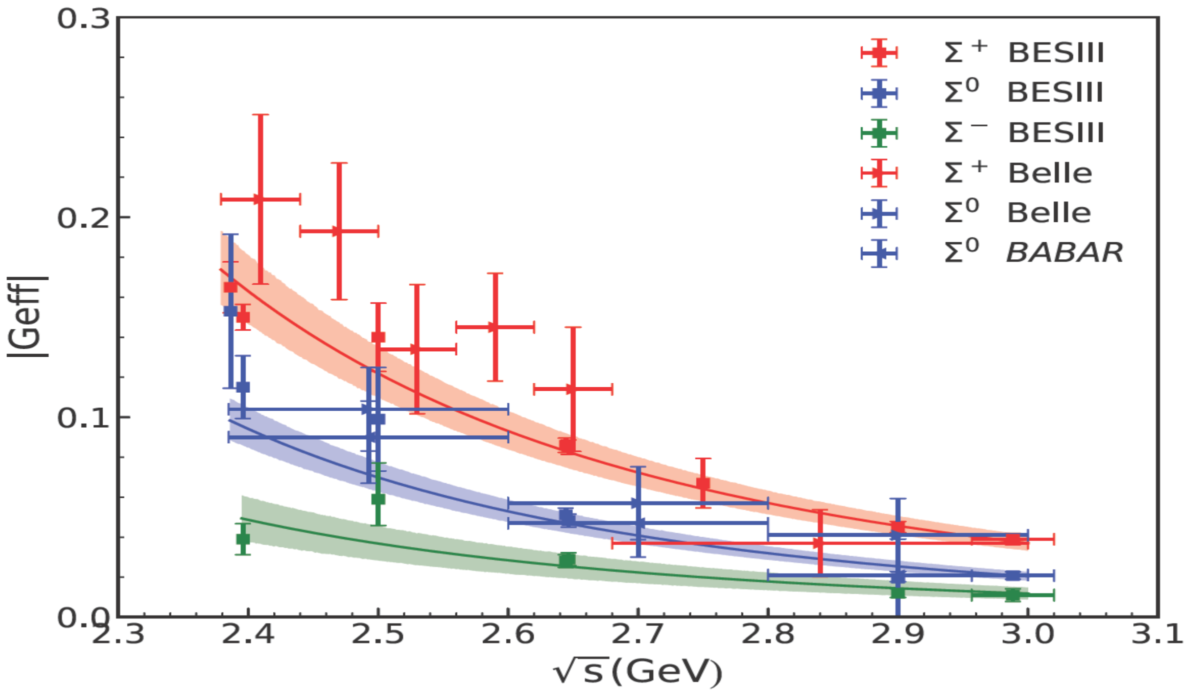
$$
\begin{aligned}
F_1^{\Sigma^+} &= g(q^2)(f_1^{\Sigma^+} + \frac{\beta_\rho}{\sqrt{2}}B_\rho - \frac{\beta_{\omega\phi}}{\sqrt{3}}B_{\omega\phi}), \\
F_2^{\Sigma^+} &= g(q^2)(f_2^{\Sigma^+}B_\rho - \frac{\alpha_{\omega\phi}}{\sqrt{3}}B_{\omega\phi}), \\
F_1^{\Sigma^-} &= g(q^2)(f_1^{\Sigma^-} - \frac{\beta_\rho}{\sqrt{2}}B_\rho - \frac{\beta_{\omega\phi}}{\sqrt{3}}B_{\omega\phi}), \\
F_2^{\Sigma^-} &= g(q^2)(f_2^{\Sigma^-}B_\rho - \frac{\alpha_{\omega\phi}}{\sqrt{3}}B_{\omega\phi}), \\
F_1^{\Sigma^0} &= g(q^2)(\frac{\beta_{\omega\phi}}{\sqrt{3}} - \frac{\beta_{\omega\phi}}{\sqrt{3}}B_{\omega\phi}), \\
F_2^{\Sigma^0} &= g(q^2)\mu_{\Sigma^0}B_{\omega\phi},
\end{aligned}
$$

$$
\begin{aligned}
B_\rho &= \frac{m_\rho^2}{m_\rho^2 - q^2 - i m_\rho \Gamma_\rho}, \\
B_{\omega\phi} &= \frac{m_{\omega\phi}^2}{m_{\omega\phi}^2 - q^2 - i m_{\omega\phi}\Gamma_{\omega\phi}},
\end{aligned}
$$

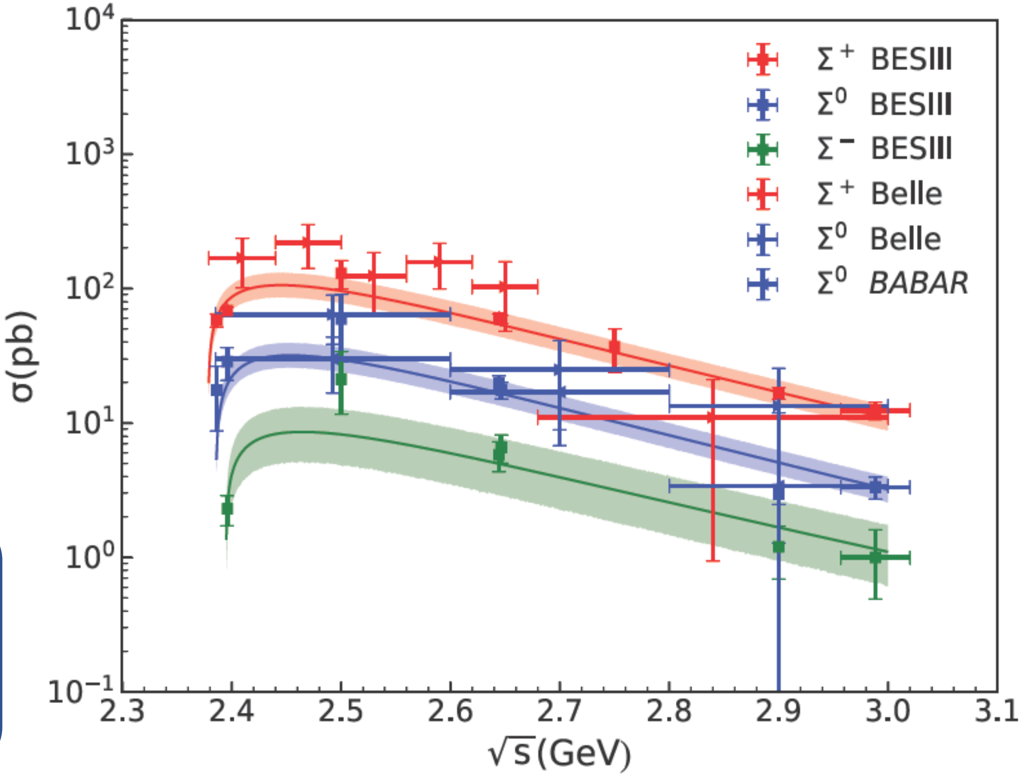
$$
f_1^{\Sigma^+} = 1 - \frac{\beta_\rho}{\sqrt{2}} + \frac{\beta_{\omega\phi}}{\sqrt{3}}, \quad f_2^{\Sigma^+} = 2.112 + \frac{\alpha_{\omega\phi}}{\sqrt{3}},
$$

$$
f_1^{\Sigma^-} = -1 + \frac{\beta_\rho}{\sqrt{2}} + \frac{\beta_{\omega\phi}}{\sqrt{3}}, \quad f_2^{\Sigma^-} = -0.479 + \frac{\alpha_{\omega\phi}}{\sqrt{3}}
$$

EMFFs of Σ^+, Σ^-, and Σ^0 baryons: Numerical results



Parameter	Value	Parameter	Value
γ (GeV^{-2})	0.527 ± 0.024	$\alpha_{\omega\phi}$	-3.18 ± 0.77
$\beta_{\omega\phi}$	-0.08 ± 0.06	β_ρ	1.63 ± 0.07



With the same value of γ, we can describe all the current experimental data on Σ^+, Σ^-, and Σ^0 EMFFs.

Bing Yan, Cheng Chen, and J. J. Xie, **Phys. Rev. D107, 076008 (2023).**

Chinese Physics Letters **41**, 021302 (2024) **Express Letter**

$e^+e^- \to \Lambda_c^+\bar{\Lambda}_c^-$ Cross Sections and the Λ_c^+ Electromagnetic Form Factors within the Extended Vector Meson Dominance Model

Cheng Chen(陈诚)[1,2*], Bing Yan(闫冰)[1,3*], and Ju-Jun Xie(谢聚军)[1,2,4*]

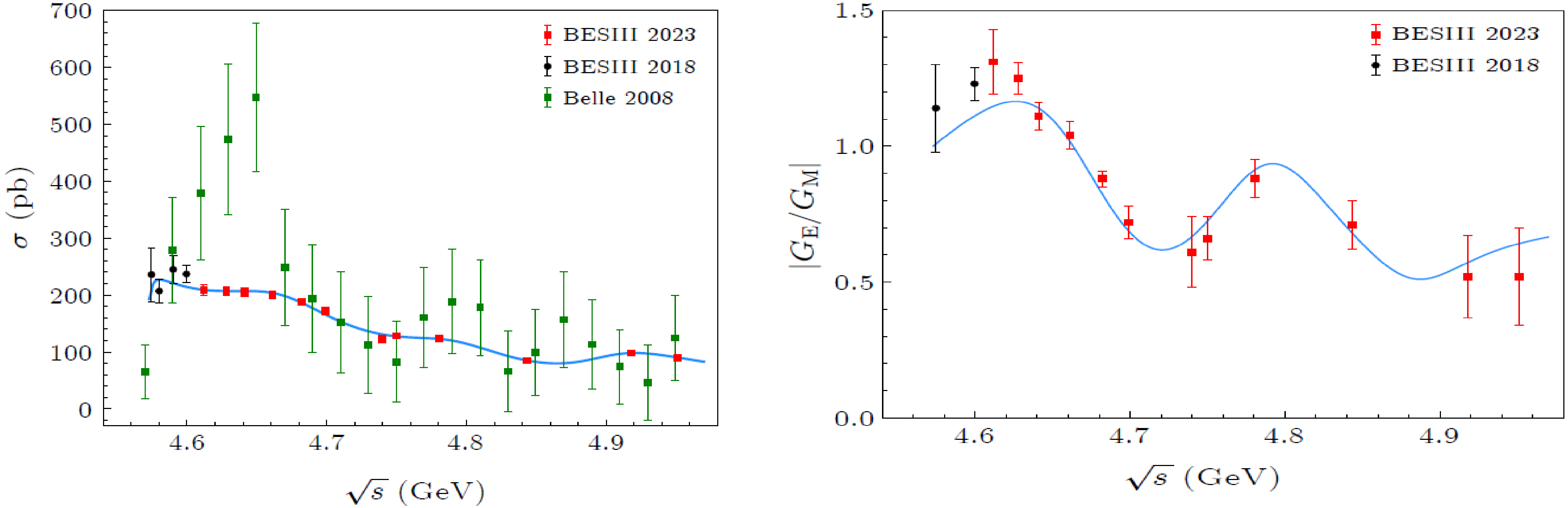
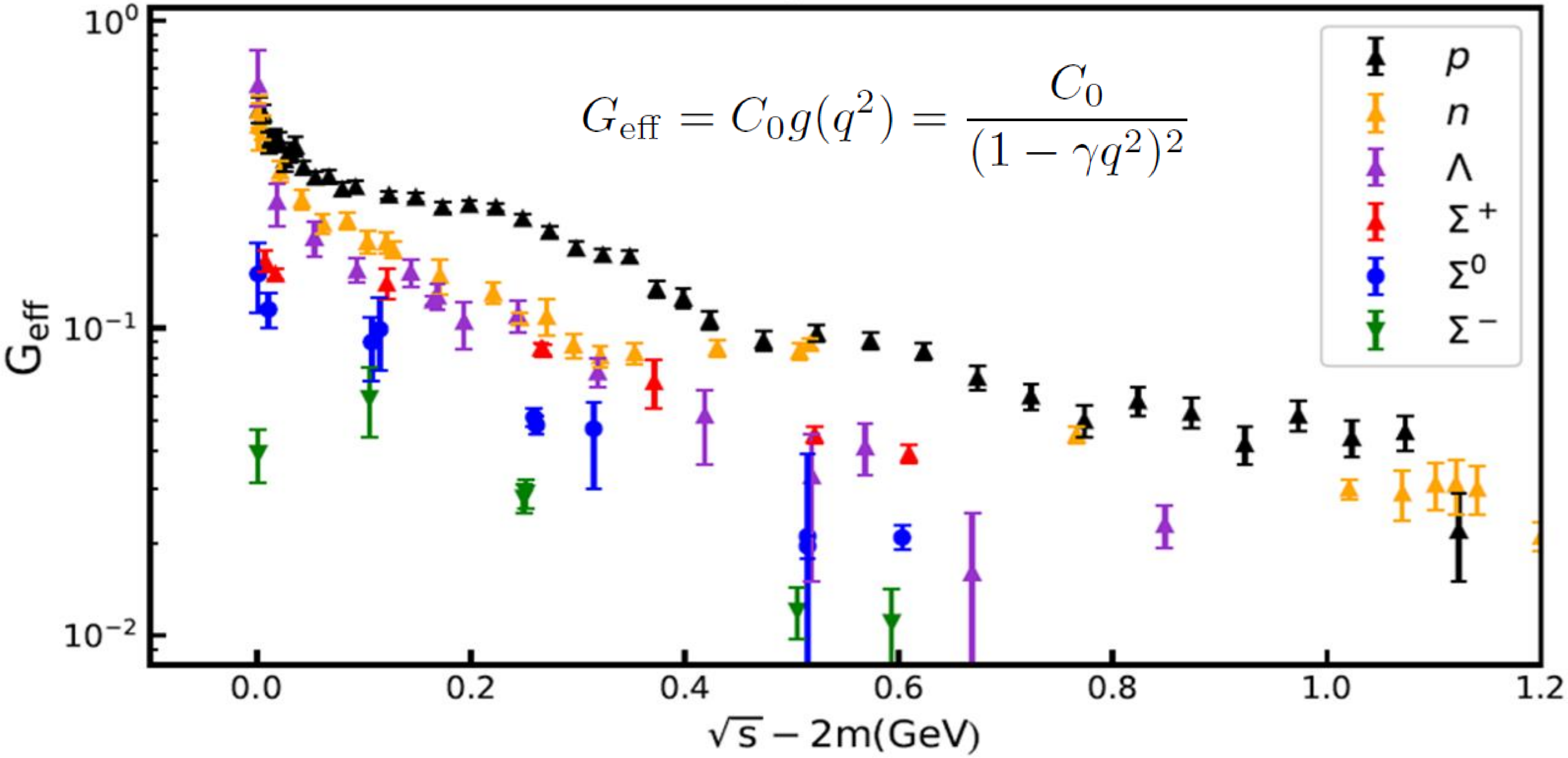


Table 1. Masses and widths of the charmonium-like states considered in this work.

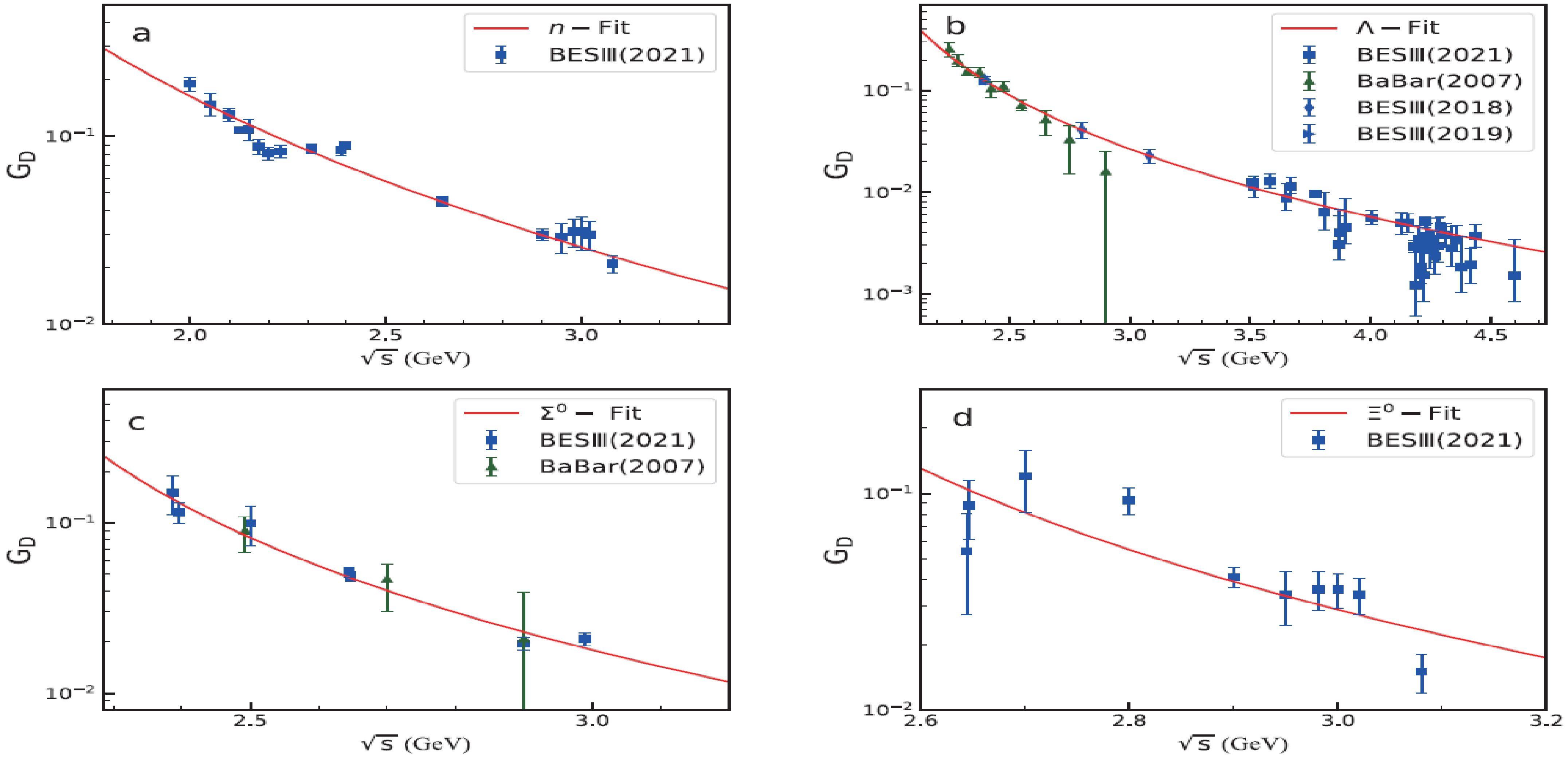
State	Mass M_R (MeV)	Width Γ_R (MeV)	References
$\psi(4500)$	4500	125	[33]
$\psi(4660)$	4670	115	[24]
$\psi(4790)$	4790	100	[35]
$\psi(4900)$	4900	100	[36–38]

Dipole behavior of baryon effective form factors



$$G_D(q^2) = \frac{c_0}{(1 - \gamma q^2)^2}$$

Parameter	n	Λ	Σ^0	Ξ^0
γ	1.41 (fixed)	0.34 ± 0.08	0.26 ± 0.01	0.21 ± 0.02
c_0	3.48 ± 0.06	0.11 ± 0.01	0.033 ± 0.007	0.023 ± 0.008
χ^2/dof	4.3	2.4	1.1	3.0



A.X. Dai, Z.Y. Li, L. Chang and J.J. Xie, Chin. Phys. C 46, 073104 (2022).

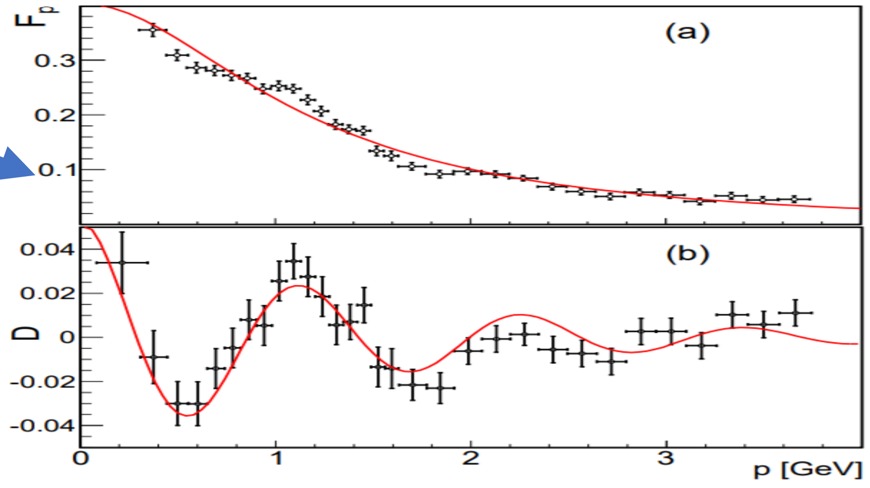
"Oscillation" of baryon effective form factors

2015, Andrea Bianconi et al., Phys. Rev. Lett., 2015, 114(23): 232301.

$$G_{eff} = F_{3p} + F_{osc} \quad \rightarrow \quad F_{osc} = data \; - G_D$$

$$F_{3p}(s) = \frac{F_0}{\left(1+\frac{s}{m_a^2}\right)\left(1-\frac{s}{m_0^2}\right)^2},$$

$$F_{osc}(p(s)) = Ae^{-Bp}\cos(Cp+D).$$

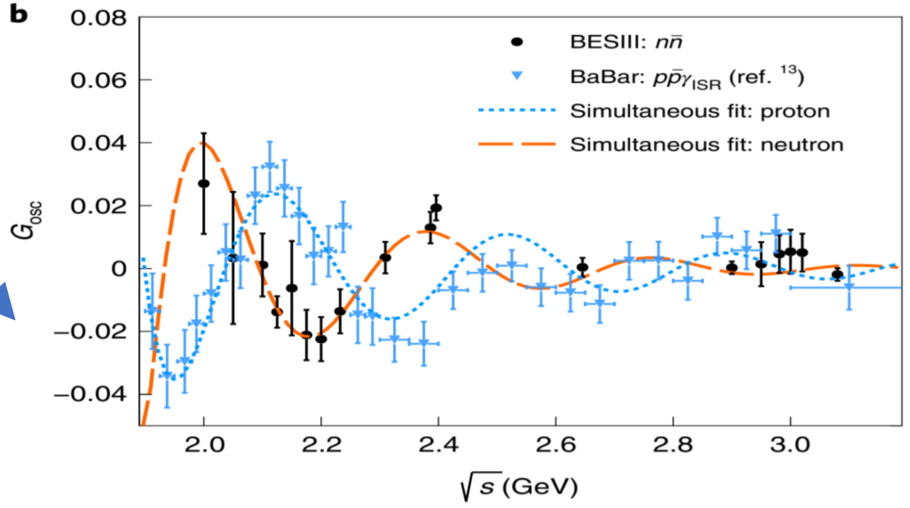


2021, BESIII Collaboration, Nature Phys., 2021, 17(11): 1200-1204.

$$data = G_{eff} = G_D + F_{osc}$$

$$\rightarrow \quad F_{osc} = data \; - G_D$$

$$F_{osc}^{n,p} = A^{n,p}\exp\left(-B^{n,p}p\right)\cos\left(Cp + D^{n,p}\right)$$



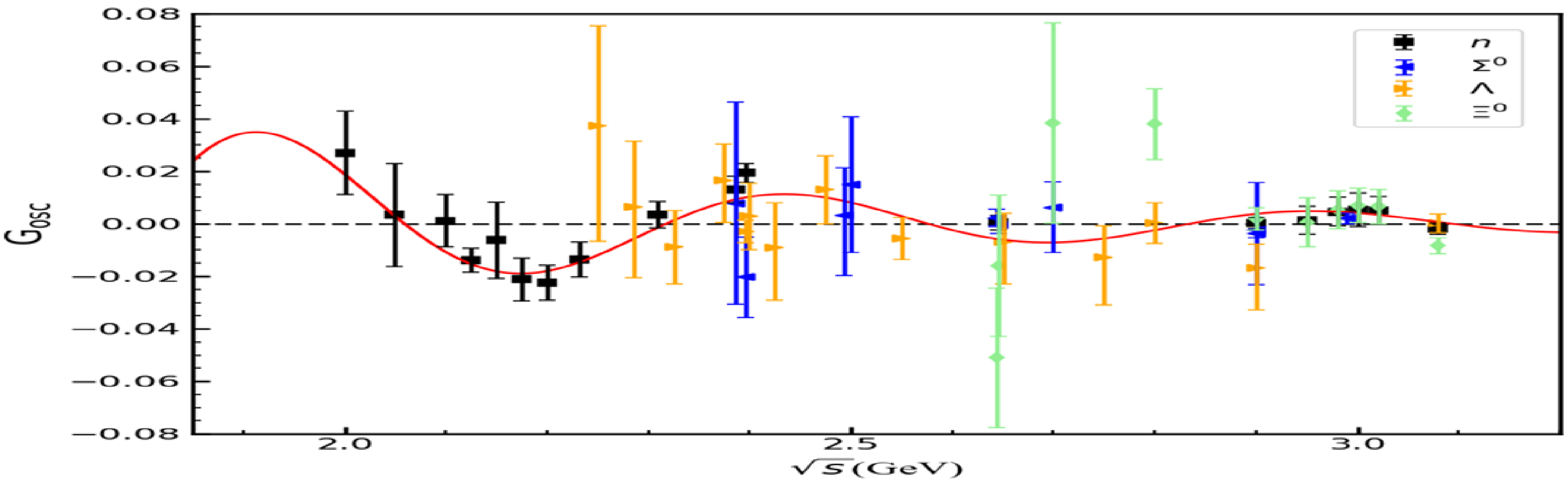
New parametrization for the "oscillation"

$$G_D(q^2) = \frac{c_0}{(1 - \gamma q^2)^2} \qquad G_{osc} = A \cdot \frac{c_0}{(1-\gamma \cdot s)^2} \cdot \cos\left(C \cdot \sqrt{s} + D\right)$$

$$G_{\rm eff}(s) = G_{\rm D}(s) + G_{\rm osc}(s) = \frac{c_0}{(1-\gamma s)^2}\left(1 + A\cos(C\sqrt{s} + D)\right)$$

$data = G_{eff} = G_D + G_{osc}$

$\rightarrow$ $G_{osc} = data - G_D$



A.X. Dai, Z.Y. Li, L. Chang and J.J. Xie, Chin. Phys. C 46, 073104 (2022).

New experimental results

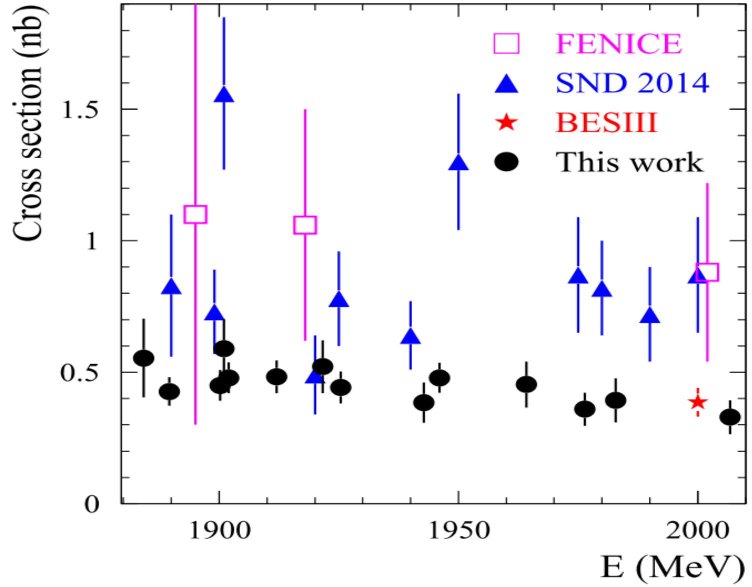
Eur. Phys. J. C (2022) 82:761
https://doi.org/10.1140/epjc/s10052-022-10696-0

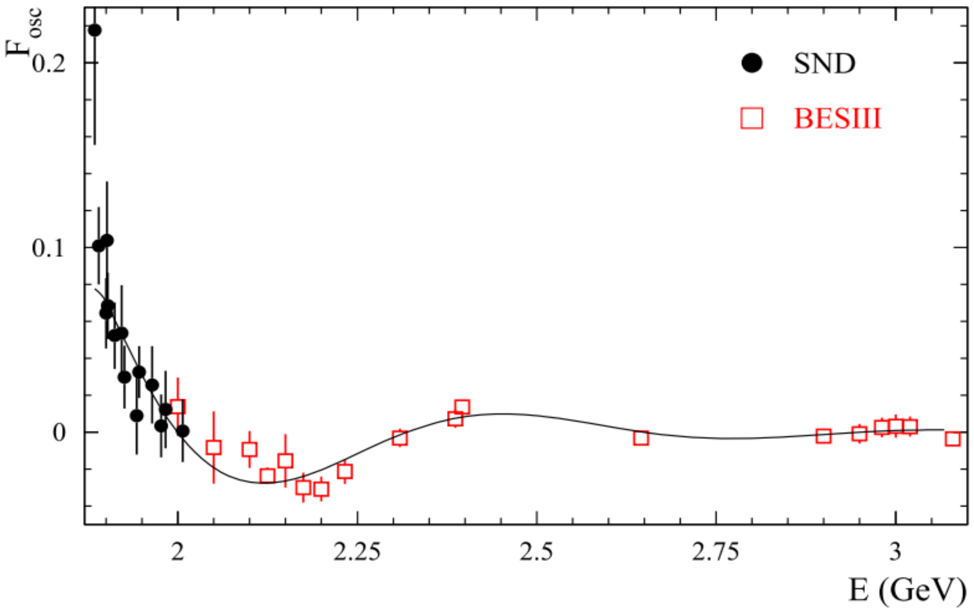
THE EUROPEAN PHYSICAL JOURNAL C

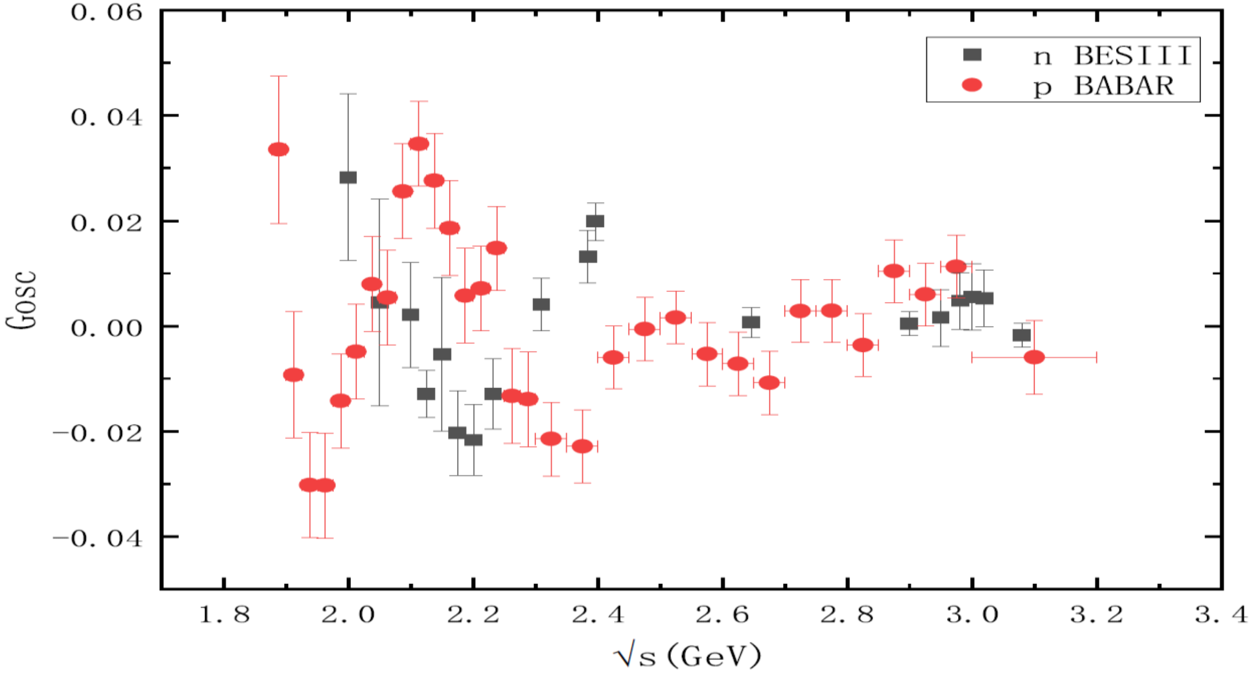
Regular Article - Experimental Physics

Experimental study of the $e^+e^- \to n\bar{n}$ process at the VEPP-2000 e^+e^- collider with the SND detector

SND Collaboration

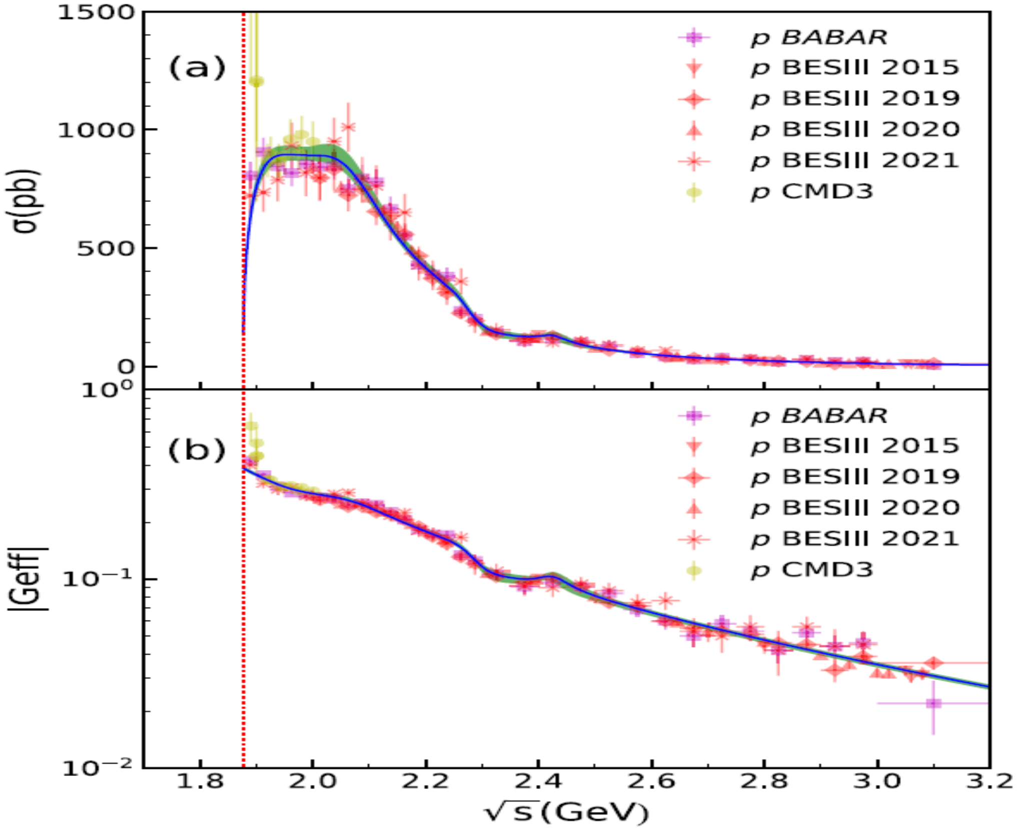






Nucleon: VMD

PHYSICAL REVIEW D **109,** 036033 (2024)



Understanding oscillating features of the timelike nucleon electromagnetic form factors within the extending vector meson dominance model

Bing Yan,[1,2] Cheng Chen,[1,3] Xia Li,[2] and Ju-Jun Xie[1,3,4,*]

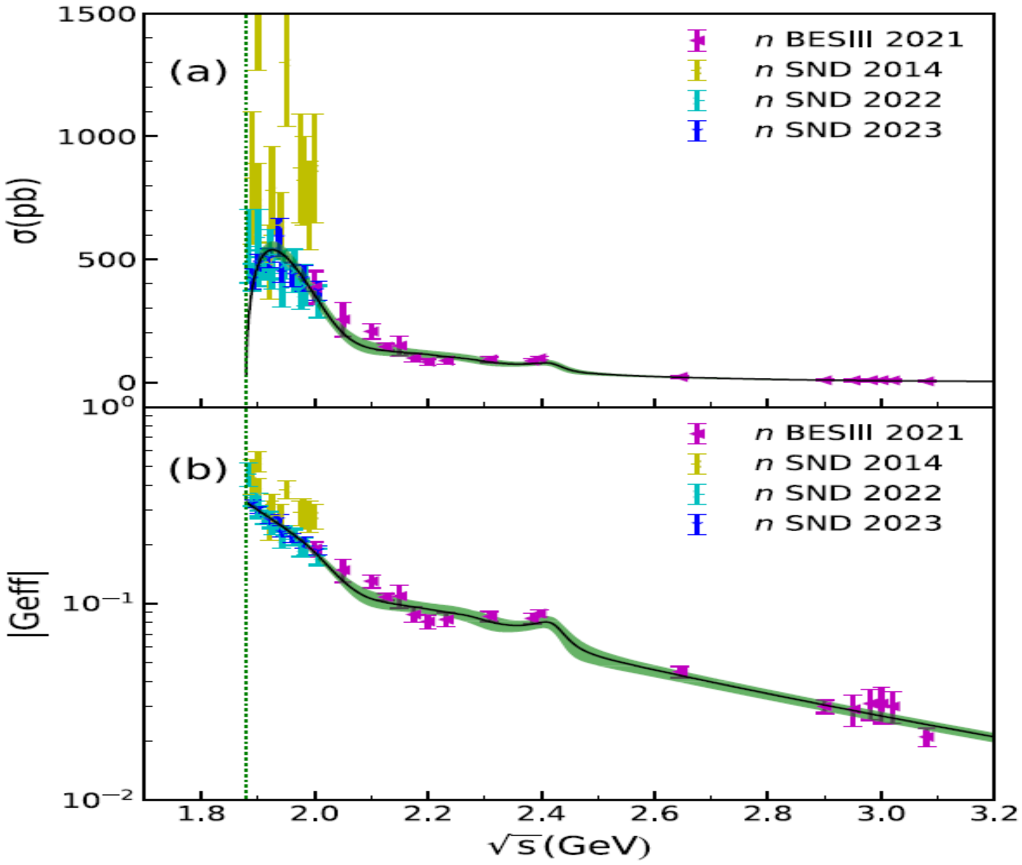


TABLE I. Masses and widths of the excited vector states used in this work.

State	Mass (MeV)	Width (MeV)	References
$\rho(2D)$	2040	202	[57,61]
$\omega(3D)$	2283	94	[58]
$\omega(5S)$	2422	69	[58]

Summary

1、Threshold enhancement

a) Final state interaction   b) Flatté (strong coupling)

$$g(q^2) = \frac{1}{(1-\gamma q^2)^2}$$

QCD VBB vertex

2、 "Oscillation" of baryon effective form factors

a) Phenomenology   b) **Vector states**

A form factor F_α is applied

$$F_\alpha(k^2) = \left(\frac{\Lambda_\alpha^2 - m_\alpha^2}{\Lambda_\alpha^2 + k^2}\right)^{n_\alpha}$$

R. Machleidt, K. Holinde and C. Elster, The Bonn Meson Exchange Model for the Nucleon Nucleon Interaction, Phys. Rept. 149, 1-89 (1987).

Thank you very much for your attention!