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Southern Center for Nuclear-Science Theory

中国科学院近代物理研究所
Institute of Modern Physics, Chinese Academy of Sciences

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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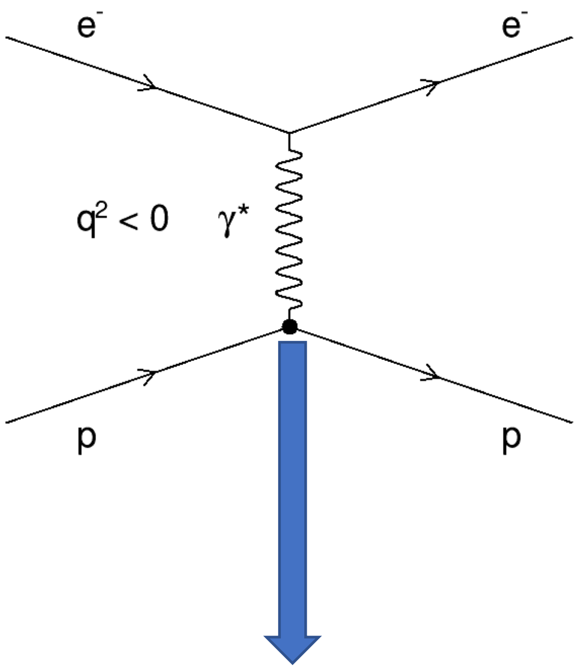
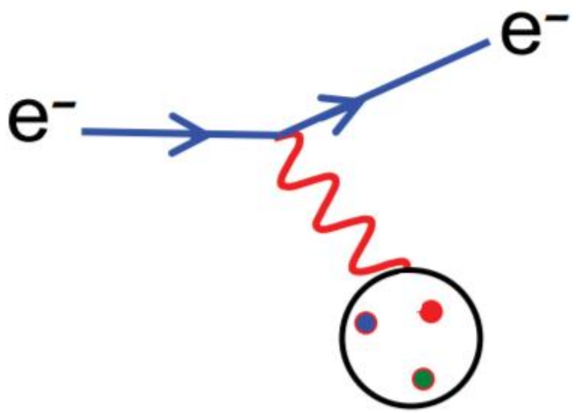
2024年10月19日@第九届手征有效场论研讨会
湖南长沙

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

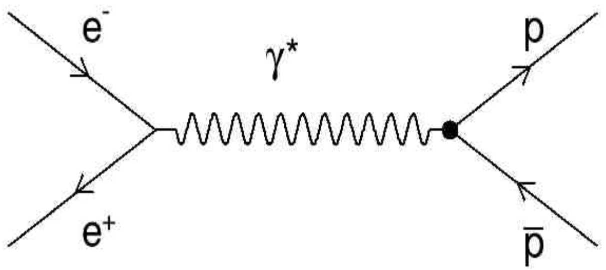
F_2^N: Pauli form factor

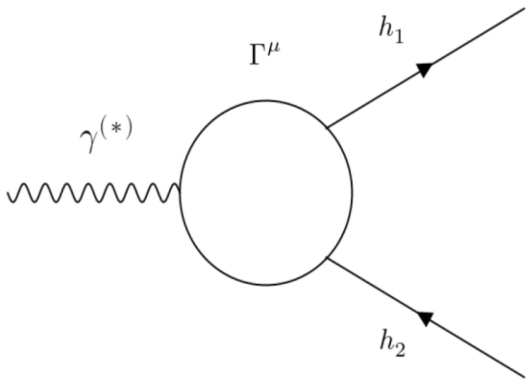
$$G_E^N(Q^2) = F_1^N(Q^2) - \tau F_2^N(Q^2)\ ,\ \ G_M^N(Q^2) = F_1^N(Q^2) + F_2^N(Q^2)\,,\ \ \tau = \frac{Q^2}{4M_N^2}$$

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

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).**

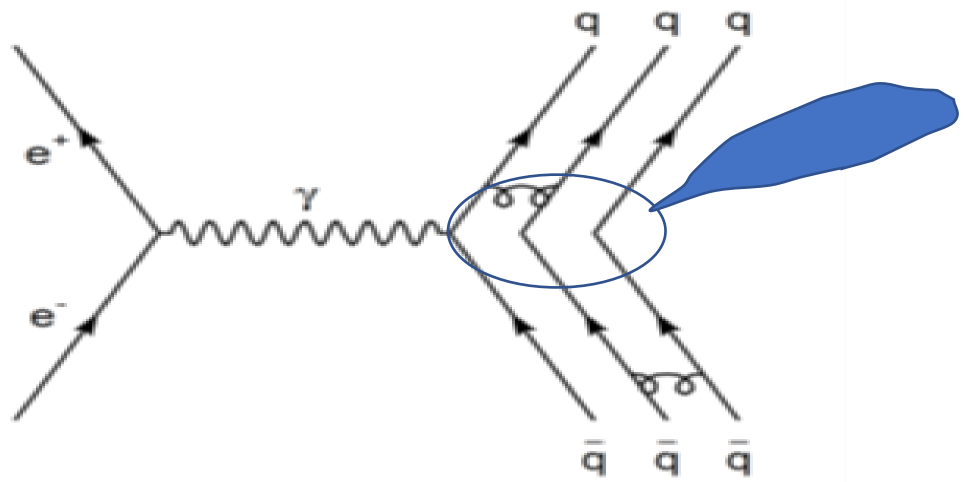
Electromagnetic form factors (time-like)





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

$$\sigma^{th}_{e^+e^-\to N\bar{N}} = \frac{\alpha^2\beta}{4q^2} C_N(q^2)\int d\Omega\left[|G_M^N(q^2)|^2(1+\cos^2\theta) + |G_E^N(q^2)|^2\frac{\sin^2\theta}{\tau}\right]$$
$$= \frac{4\pi\alpha^2\beta}{3q^2} C_N(q^2)\left[|G_M^N(q^2)|^2 + \frac{|G_E^N(q^2)|^2}{2\tau}\right].$$

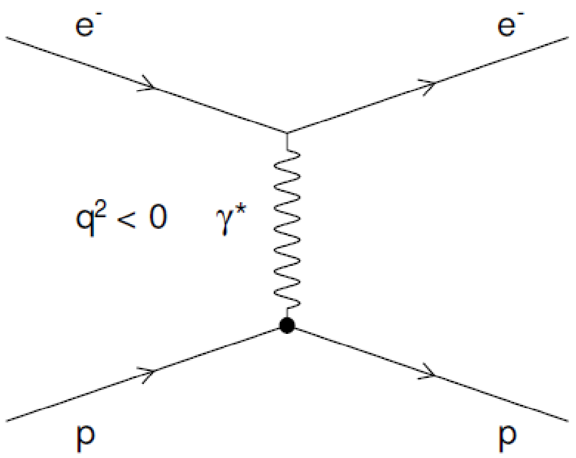


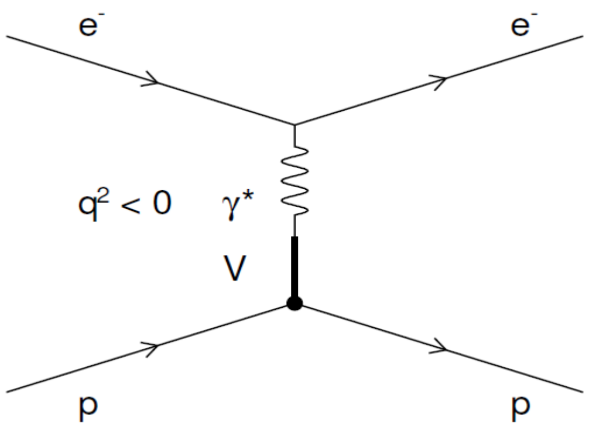
$$|G_{eff}(q^2)| = \sqrt{\frac{\sigma(q^2)}{\sigma_{point}(q^2)}} = \sqrt{\frac{|G_M(s)|^2 + \frac{2M^2}{s}|G_E(s)|^2}{1+\frac{2M^2}{s}}}$$

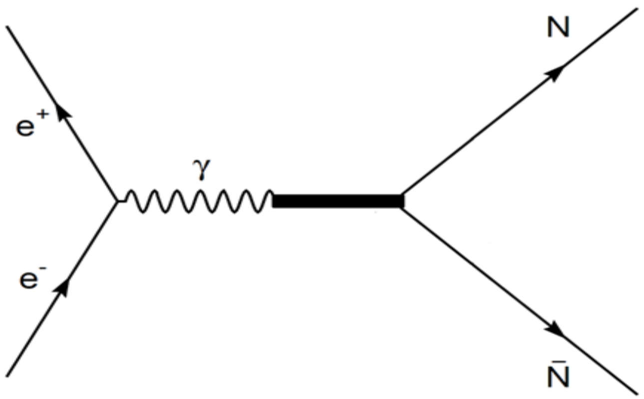
From QED to QCD

Both QED and QCD

VMD: vector meson dominance model







Dirac and Pauli isoscalar and isovector form factors are

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

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

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

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

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

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

$$G_E = F_1 - \tau F_2$$

$$G_M = F_1 + F_2$$

Volume 43B, number 3 PHYSICS LETTERS 5 February 1973

SEMI-PHENOMENOLOGICAL FITS TO NUCLEON ELECTROMAGNETIC FORM FACTORS

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The Niels Bohr Institute, University of Copenhagen, Copenhagen, Denmark 2100

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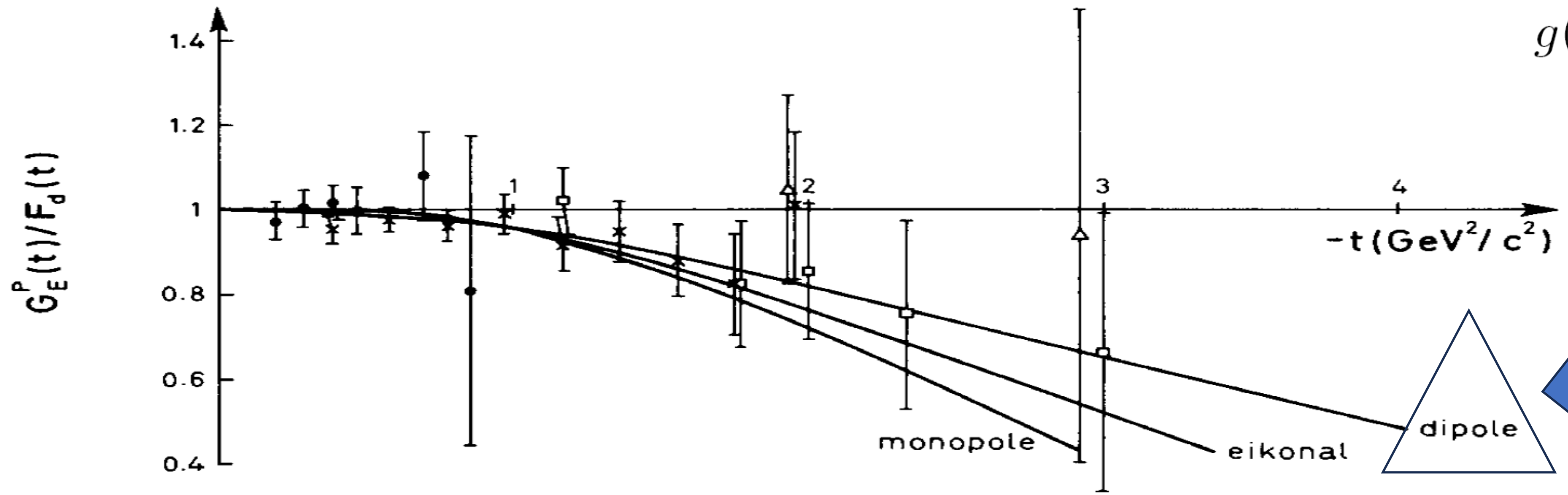
A. LANDE
Institute for Theoretical Physics, University of Groningen, Groningen, The Netherlands

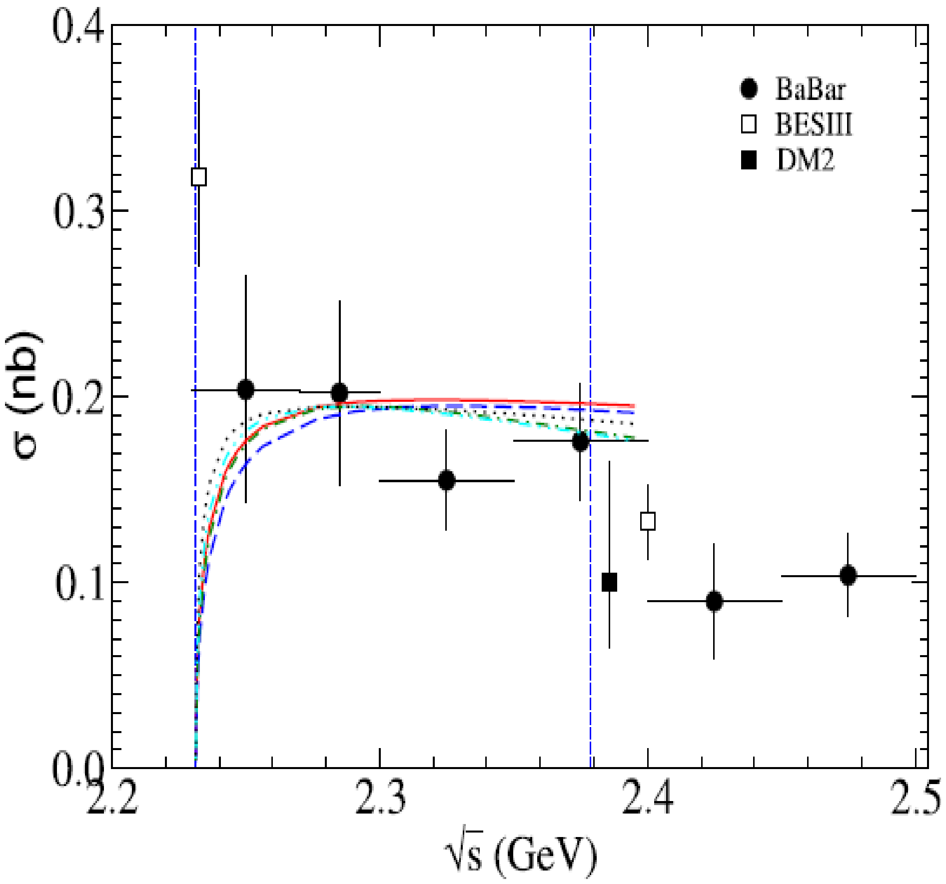
Received 31 August 1972

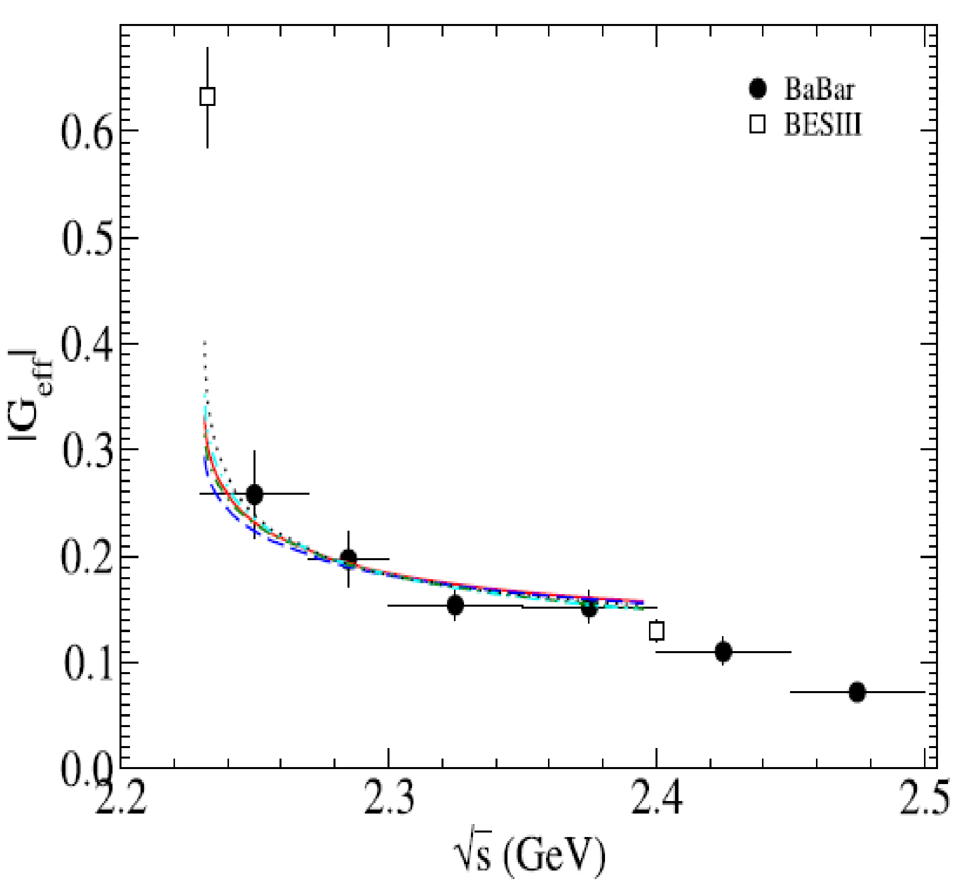
Several theoretically interesting forms of the nucleon EM form factor have been considered and found to provide quantitative descriptions of available data with as few as three adjustable parameters.



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

Λ





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

EMFFs of Λ in the VMD

$$
\begin{aligned}
F_1(Q^2) &= g(Q^2)\left[-\beta_\omega - \beta_\phi + \beta_\omega \frac{m_\omega^2}{m_\omega^2+Q^2} + \beta_\phi \frac{m_\phi^2}{m_\phi^2+Q^2} + \beta_x \frac{m_x^2}{m_x^2+Q^2}\right] \\
F_2(Q^2) &= g(Q^2)\left[(\mu_\Lambda - \alpha_\phi)\frac{m_\omega^2}{m_\omega^2+Q^2} + \alpha_\phi \frac{m_\phi^2}{m_\phi^2+Q^2} + \alpha_x \frac{m_x^2}{m_x^2+Q^2}\right] \\
g(Q^2) &= 1/(1+\gamma Q^2)^2
\end{aligned}
$$

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

$$
\begin{aligned}
G_E(q^2) &= F_1(q^2) + \tau F_2(q^2) \\
G_M(q^2) &= F_1(q^2) + F_2(q^2)
\end{aligned}
$$

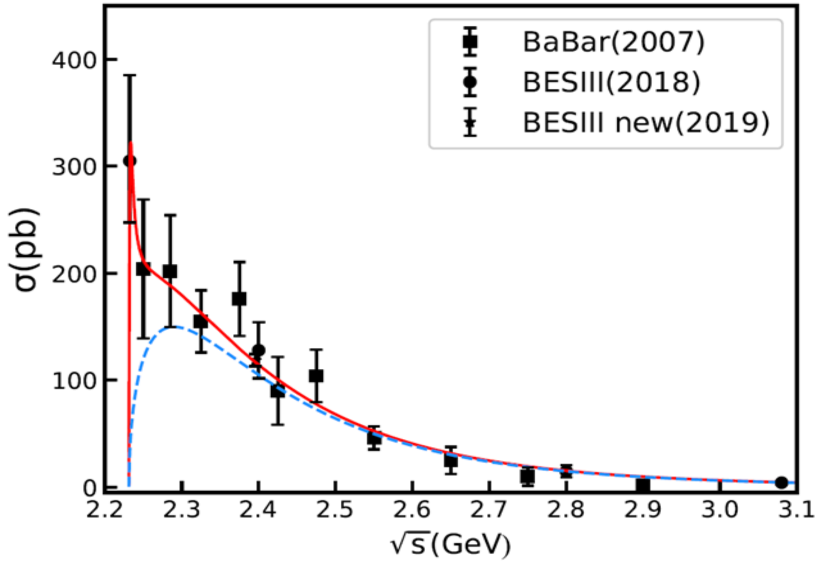
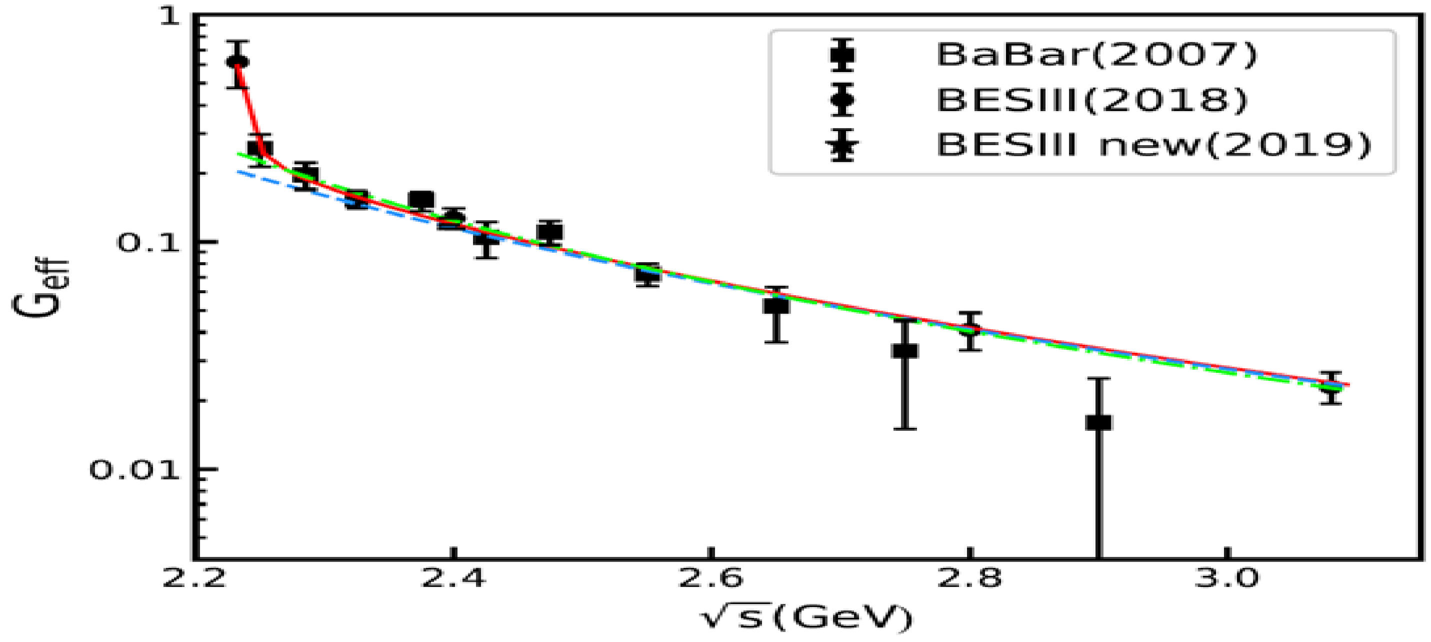


Figure: Cross section of the reaction $e^+e^- \to \bar{\Lambda}\Lambda$.

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

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

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)

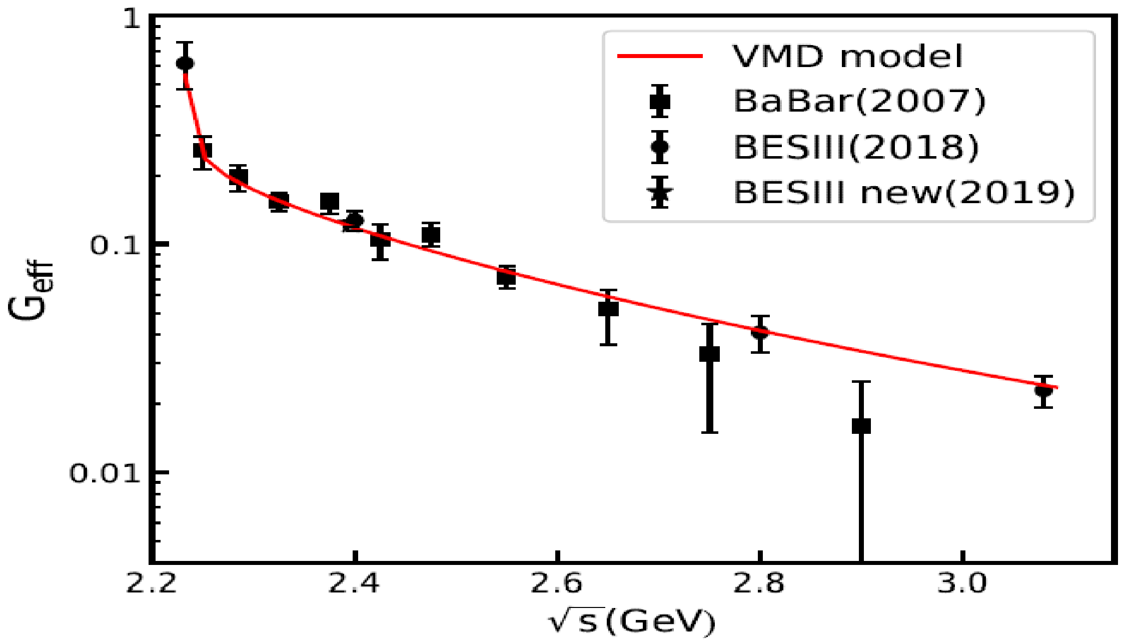


Figure: Fitting result of $|G_{eff}|$ with Flatte.

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

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

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

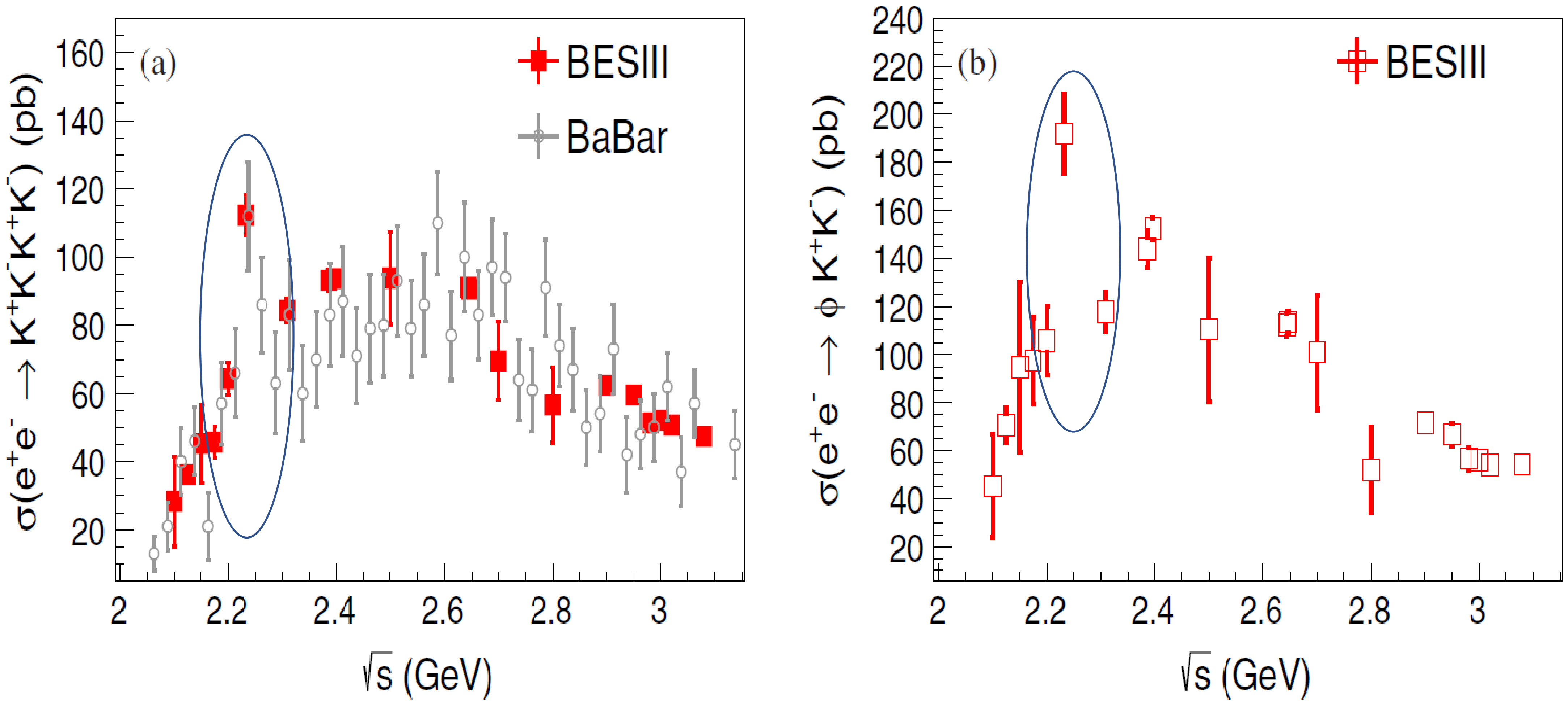
$$\Gamma_{K\bar{K}} = \begin{cases} g_K \sqrt{(1/4)m^2 - m_K^2} & \text{above threshold} \\ i g_K \sqrt{m_K^2 - (1/4)m^2} & \text{below threshold} \end{cases}$$

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

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

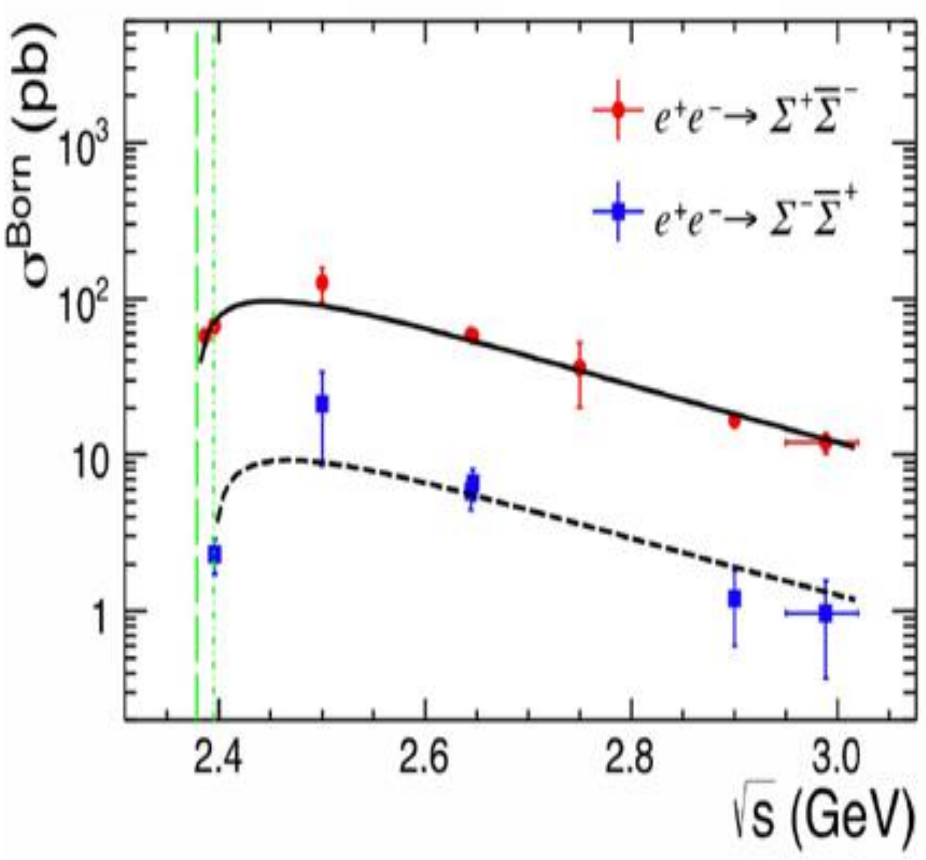
Z. Y. Li, A. X. Dai and J. J. Xie, Chin. Phys. Lett. 39, 011201 (2022).

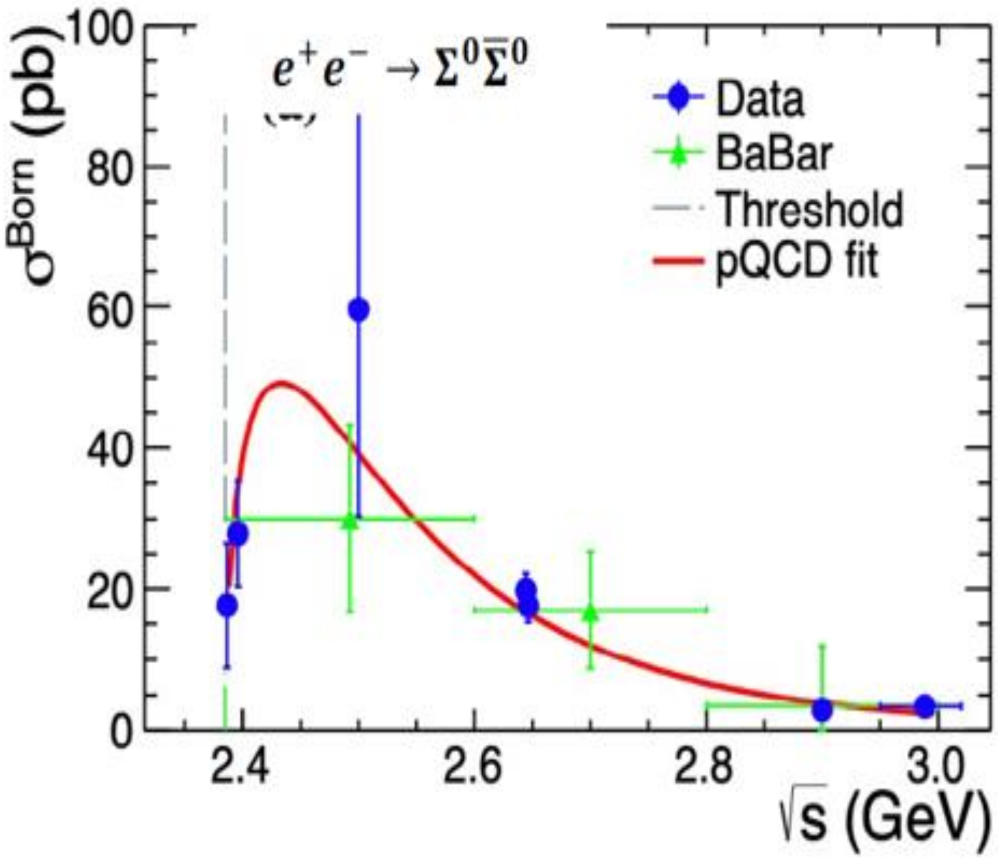
Where is the X(2231)?



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

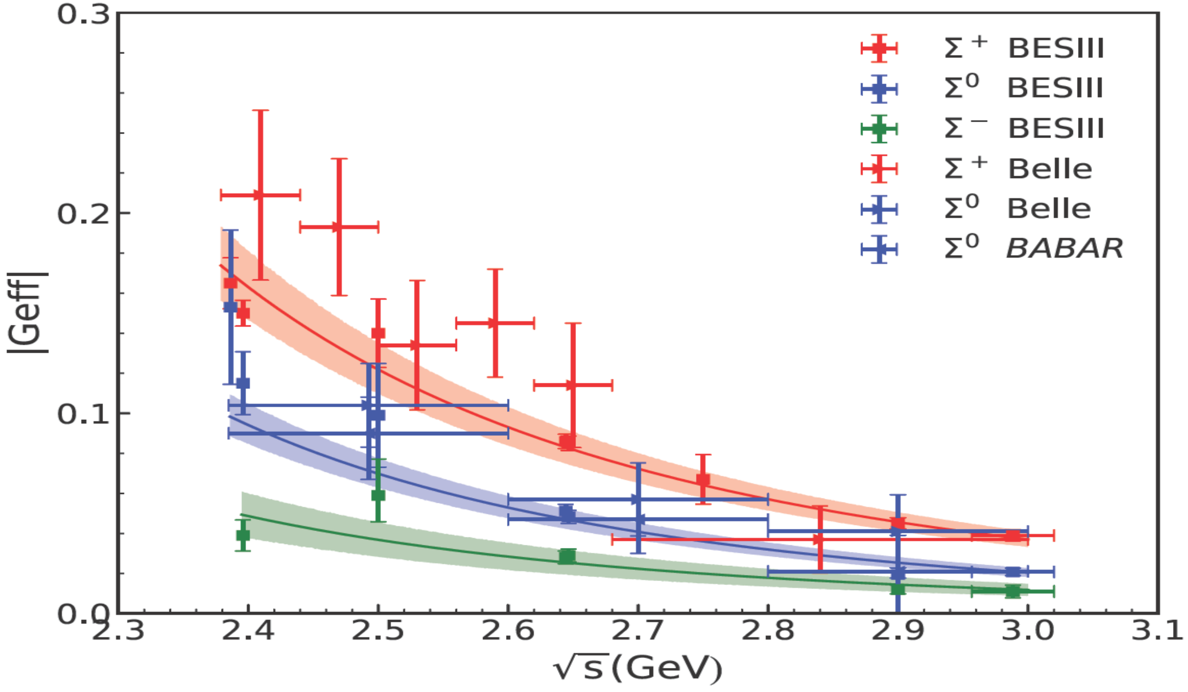
$$
\begin{aligned}
F_1^{\Sigma^+} &= g(q^2)(f_1^{\Sigma^+} + \frac{\beta_\rho}{\sqrt{2}}B_\rho - \frac{\beta_{\omega\phi}}{\sqrt{3}}B_{\omega\phi}), \\
F_2^{\Sigma^+} &= g(q^2)(f_2^{\Sigma^+}B_\rho - \frac{\alpha_{\omega\phi}}{\sqrt{3}}B_{\omega\phi}), \\
F_1^{\Sigma^-} &= g(q^2)(f_1^{\Sigma^-} - \frac{\beta_\rho}{\sqrt{2}}B_\rho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

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

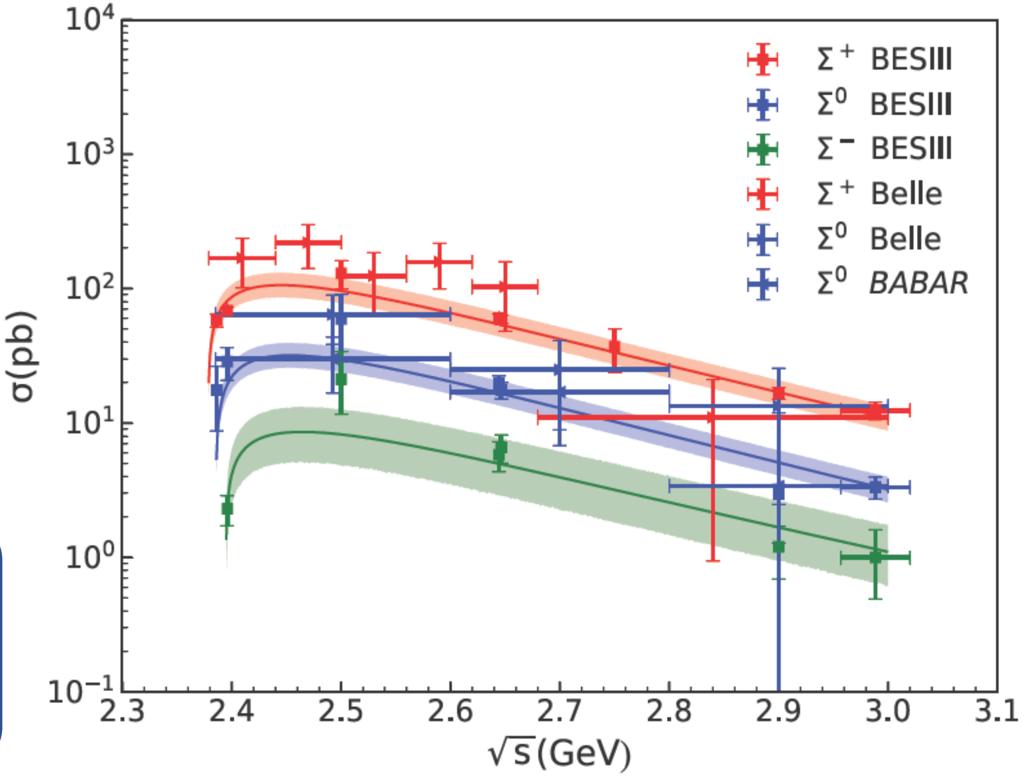
$$
f_1^{\Sigma^+} = 1 - \frac{\beta_\rho}{\sqrt{2}} + \frac{\beta_{\omega\phi}}{\sqrt{3}}, \quad f_2^{\Sigma^+} = 2.112 + \frac{\alpha_{\omega\phi}}{\sqrt{3}},
$$

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

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



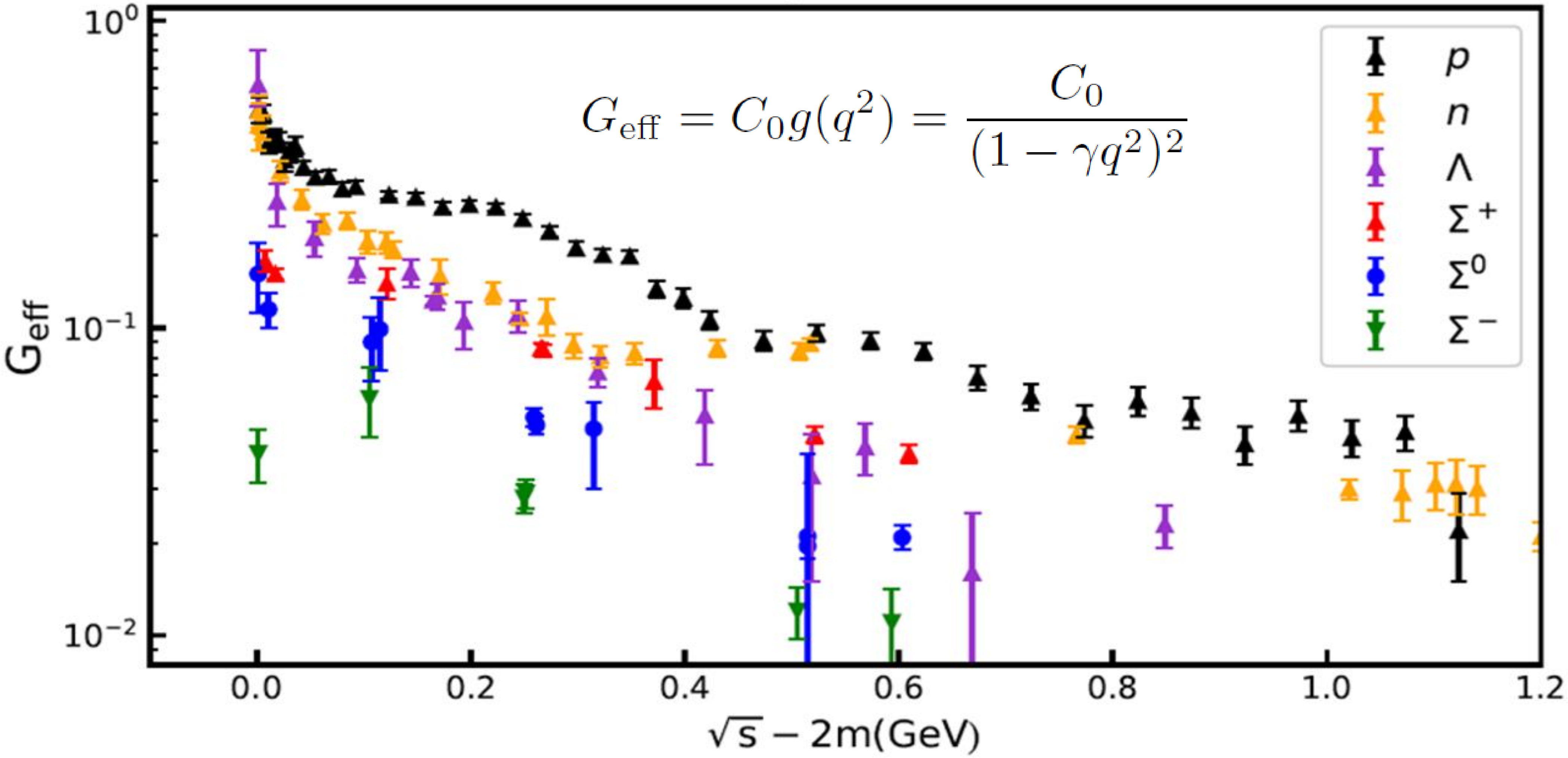
Parameter	Value	Parameter	Value
γ (GeV^{-2})	0.527 ± 0.024	$\alpha_{\omega\phi}$	-3.18 ± 0.77
$\beta_{\omega\phi}$	-0.08 ± 0.06	β_ρ	1.63 ± 0.07



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

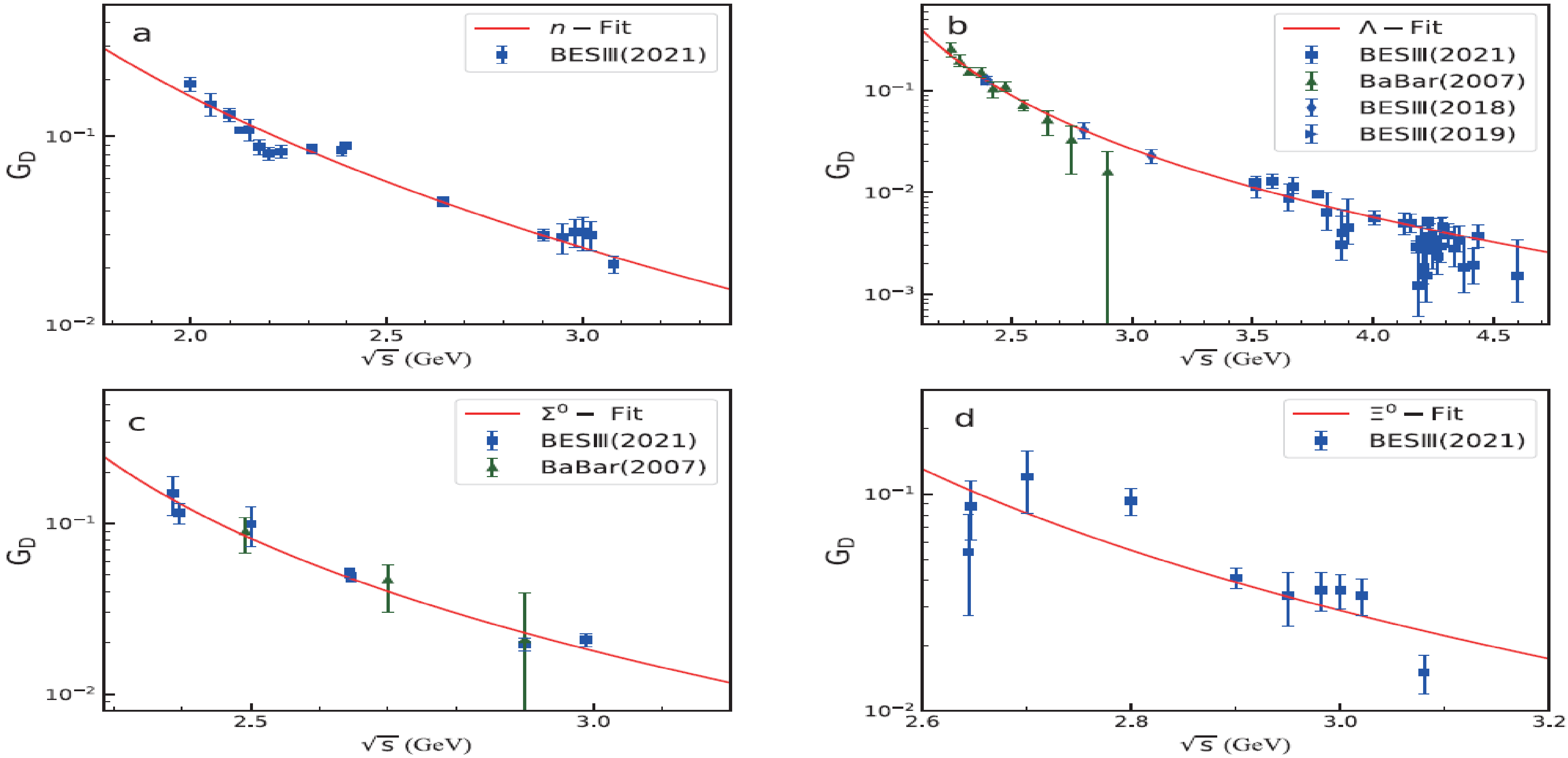
Bing Yan, Cheng Chen, and J. J. Xie, **Phys. Rev. D107, 076008 (2023).**

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).

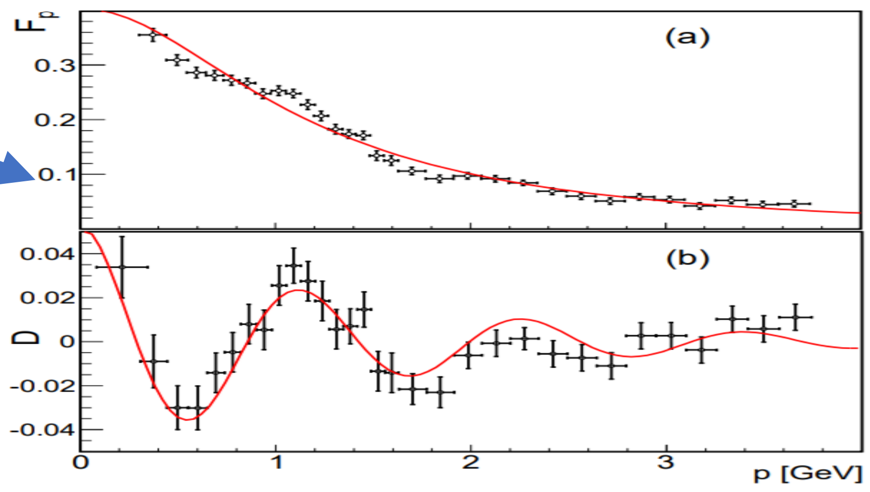
" Oscillation" of baryon effective form factors

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

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

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

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

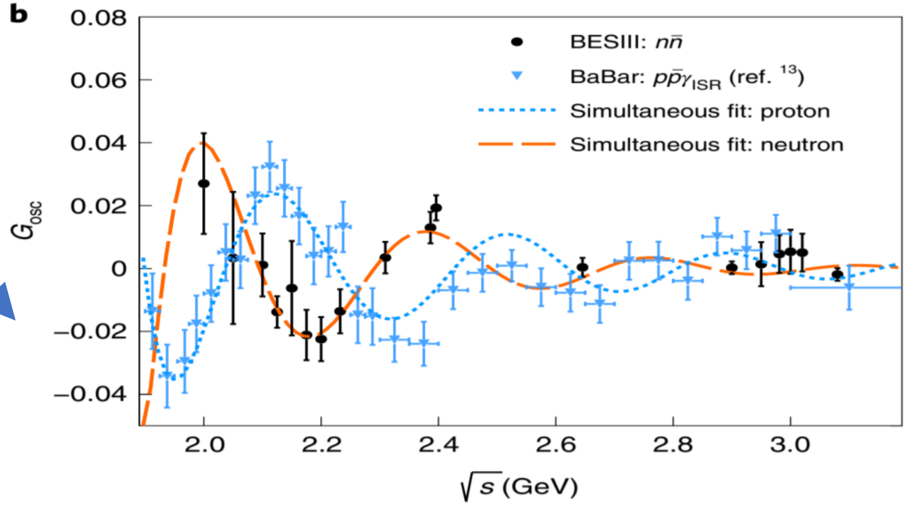


2021, BESIII Collaboration, Nature Phys., 2021, 17(11): 1200-1204.

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

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

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



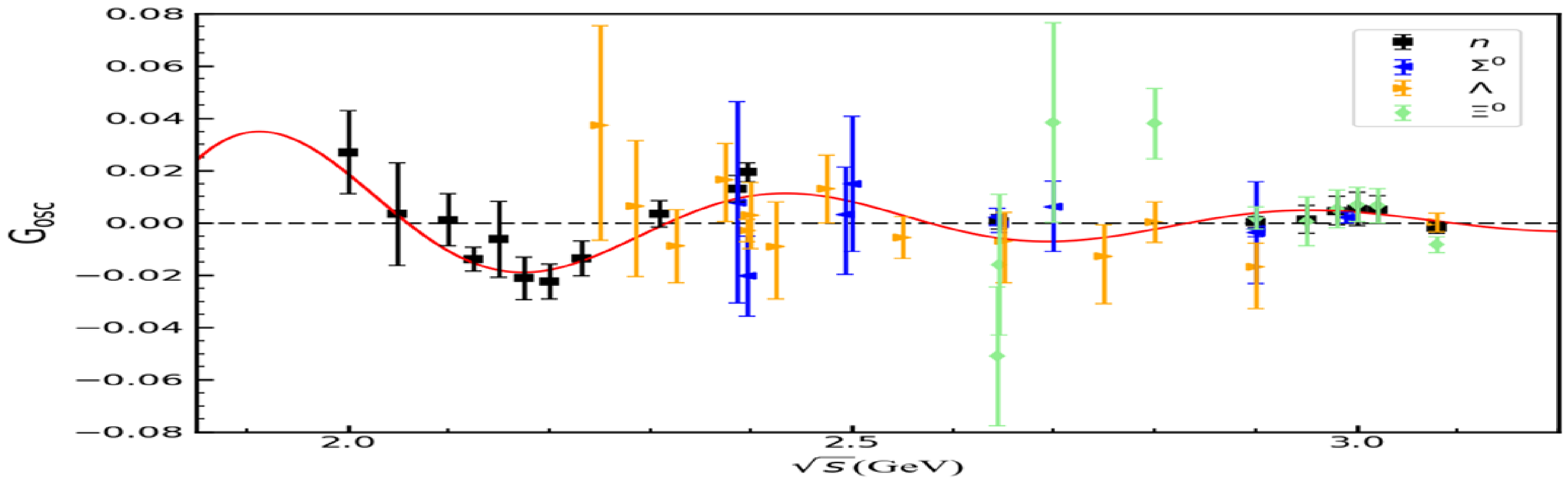
New parametrization for the "oscillation"

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

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

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

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

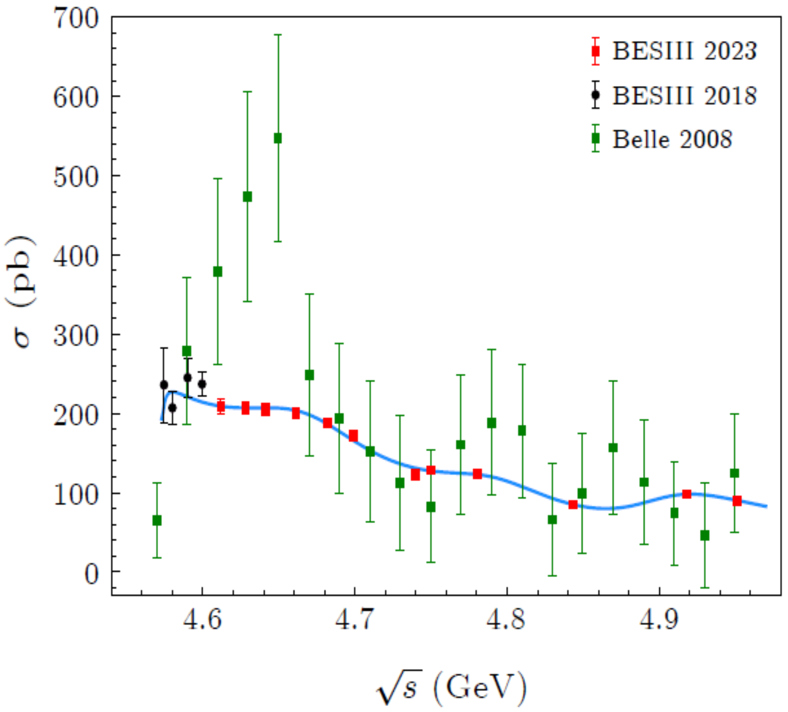


A.X. Dai, Z.Y. Li, L. Chang and J.J. Xie, Chin. Phys. C 46, 073104 (2022).

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*]



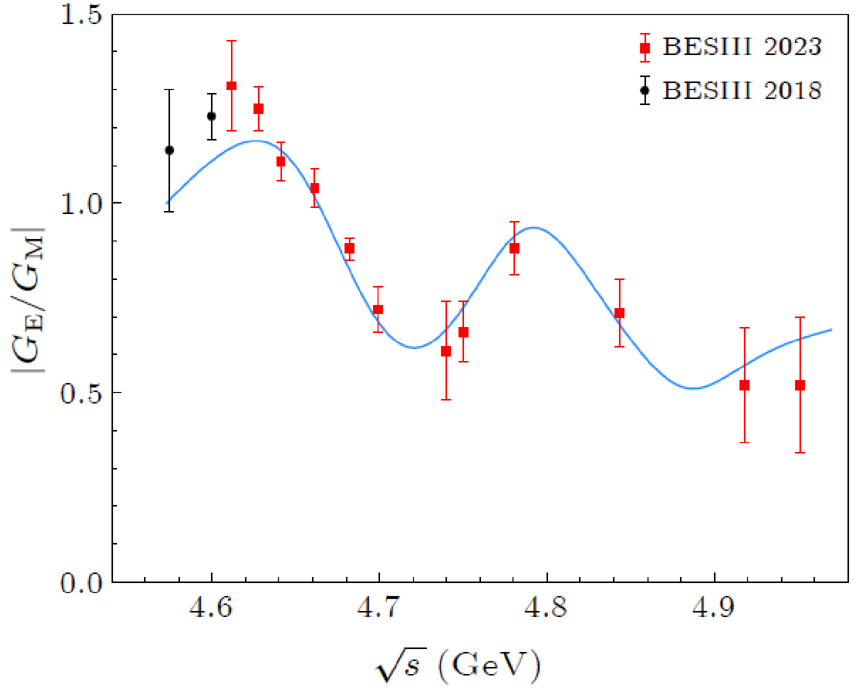


Table 1. Masses and widths of the charmonium-like states considered in this work.

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]

See more details @
21日上午第二场，分会场一，
By Cheng Chen (陈诚)

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!

南方核科学理论研究中心--建设目标

南方核科学理论研究中心为中国科学院近代物理研究所的内设机构，依托近代物理研究所，并联合广东省能源科学与技术实验室（东江实验室）共同建设。

建设目标

- ✓ **聚焦近代物理所核物理研究的重点方向和重大任务，开展相关理论研究，形成研究所理论紧密结合实验研究的新局面。**
- ✓ **为推动现有、在建和规划中的大装置升级、建设、预研，提供有力理论支撑。**

凝聚和培养一批国内外优秀理论科学家，强化理论物理对应用型学科发展和关键核心技术突破的引领和支持作用，产出和创新一批重要理论研究成果；建成国内一流国际有一定影响力的强相互作用理论研究中心，为我国乃至世界核科学事业发展做出重要贡献。

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（战略咨询和指导）

学术方向负责人

- 负责中心学术方向发展
- 组织学术活动
- 营造良好的学术风气和氛围

访问科学家、博士后、客座成员

- 中心的学术主体
- 在学术上做出应有的贡献
- 营造良好的学术风气和氛围

行政秘书 薛琴

- 负责中心日常行政工作

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
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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