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

谢 聚 军

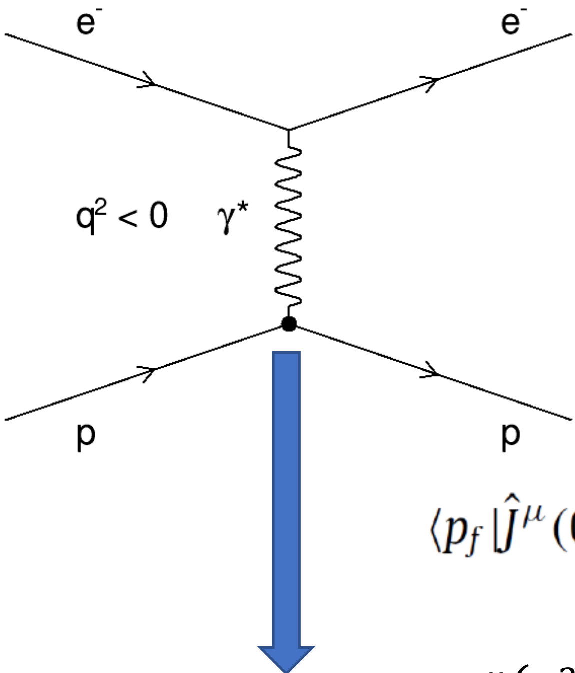
中 国 科 学 院 近 代 物 理 研 究 所

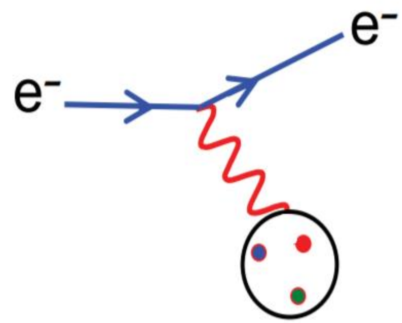
2026年7月1日@2026年超级陶粲装置研讨会 西安

Outline

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

Electromagnetic form factors (space-like)





F_1^N : Dirac form factor

F_2^N: Pauli form factor

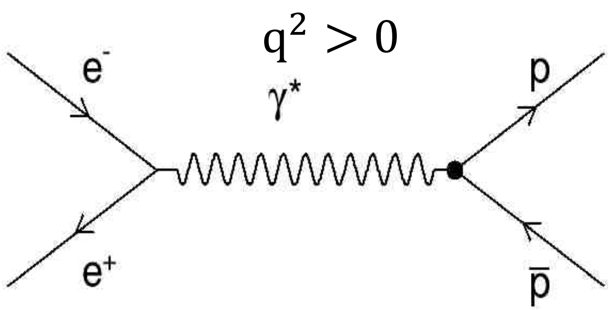
$$\langle p_f | \hat{J}^\mu(0) | p_i \rangle = \overline{u}(p_f)\left[F_1(q^2)\gamma^\mu - F_2(q^2)\frac{\sigma^{\mu\nu}q_\nu}{2M}\right]u(p_i)$$

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

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

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

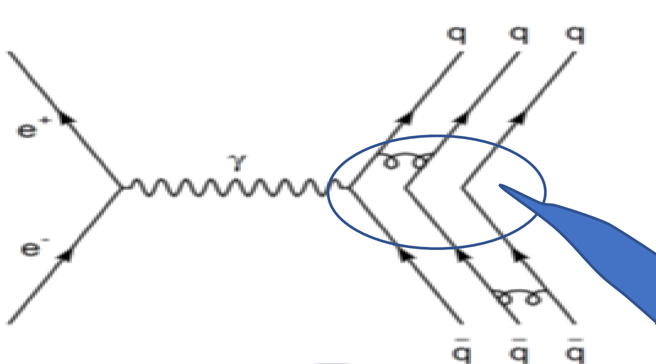
Electromagnetic form factors (time-like)



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

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

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



$$\sigma_{e^+e^-\to B\bar{B}} = \frac{4\pi\alpha^2\beta C}{3s}\left(1+\frac{1}{2\tau}\right)|G_{\text{eff}}(q^2)|^2$$

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

From QED to QCD

Both QED and QCD

VMD: vector meson dominance model

PHYSICAL REVIEW VOLUME 157, NUMBER 5 25 MAY 1967

Neutral Vector Mesons and the Hadronic Electromagnetic Current*

NORMAN M. KROLL
University of California, San Diego, La Jolla, California

AND

T. D. LEE
Columbia University, New York, New York

AND

BRUNO ZUMINO
New York University, New York, New York

(Received 6 January 1967)

FINITE-WIDTH CORRECTIONS TO THE VECTOR-MESON-DOMINANCE PREDICTION FOR $\rho \to e^+e^-$ *

G J. Gounaris and J. J Sakurai
Department of Physics, and The Enrico Fermi Institute, The University of Chicago, Chicago, Illinois

(Received 17 May 1968)

Finite-width corrections based on a generalized effective range formula for pion-pion scattering modify by a non-negligible amount the well-known relation between $\Gamma(\rho \to e^+e^-)$ and $\Gamma(\rho \to \pi\pi)$ derived on the basis of vector-meson dominance. We also present a new current-algebra prediction for the shape and magnitude of $\sigma(e^+e^- \to \pi^+\pi^-)$ and estimate the ρ-meson contribution to the Schwinger term.

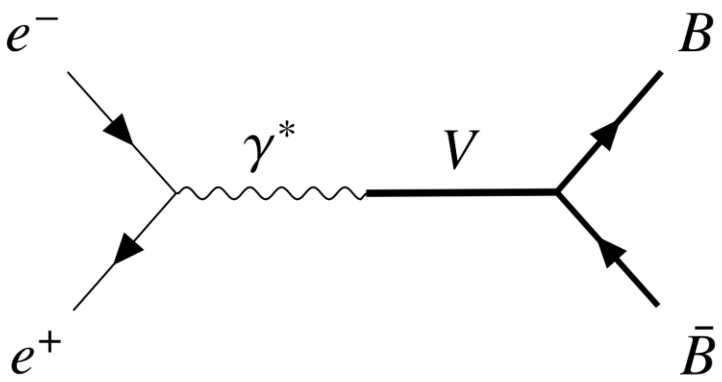
VMD: A virtual (real) photon transforms into a vector before interacting with a target.

The vector can be taken as a part of a "hadronic structure" of the photon.

VMD: vector meson dominance model

$$\mathcal{L}_{V\gamma} = e\sum_V \frac{M_V^2}{f_V} V_{\mu\nu}F^{\mu\nu}$$

$$\mathcal{L}_{BBV} = g_V \bar{\psi}\gamma_\mu \psi V^\mu + \frac{\kappa_V}{4M}\bar{\psi}\sigma_{\mu\nu}(\partial^\mu V^\nu - \partial^\nu V^\mu)$$

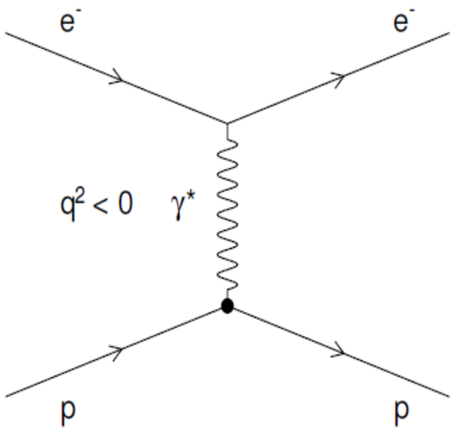


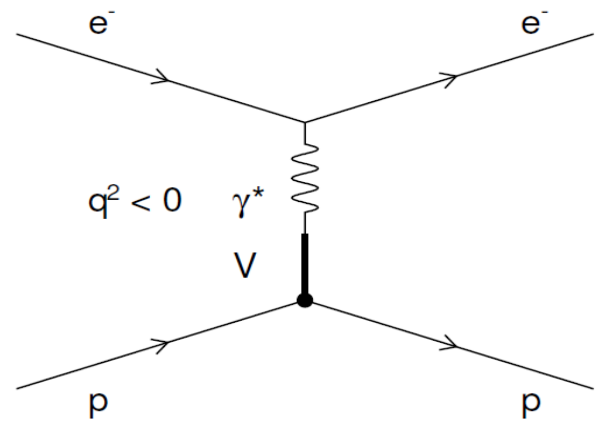
$$\Gamma_\mu^V = g_V\gamma_\mu + i\frac{\kappa_V}{2M}\sigma_{\mu\nu}q^\nu$$

$$\Gamma_\mu = \gamma_\mu F_1(q^2) + i\frac{F_2(q^2)}{2M}\sigma_{\mu\nu}q^\nu = \frac{1}{f_V}\frac{M_V^2}{M_V^2 - q^2}\Gamma_\mu^V$$

$$\Rightarrow \begin{cases} F_1(q^2) = \sum_V \beta_V \dfrac{M_V^2}{M_V^2 - q^2}, & \beta_V = \dfrac{g_V}{f_V} \\ F_2(q^2) = \sum_V \alpha_V \dfrac{M_V^2}{M_V^2 - q^2}, & \alpha_V = \dfrac{\kappa_V}{f_V} \end{cases}$$

VMD for nucleon





Dirac and Pauli isoscalar and isovector form factors are

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

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

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

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

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

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

$$G_E = F_1 - \tau F_2$$

$$G_M = F_1 + F_2$$

SEMI-PHENOMENOLOGICAL FITS TO NUCLEON ELECTROMAGNETIC FORM FACTORS

F. IACHELLO* and A.D. JACKSON**
The Niels Bohr Institute, University of Copenhagen, Copenhagen, Denmark 2100

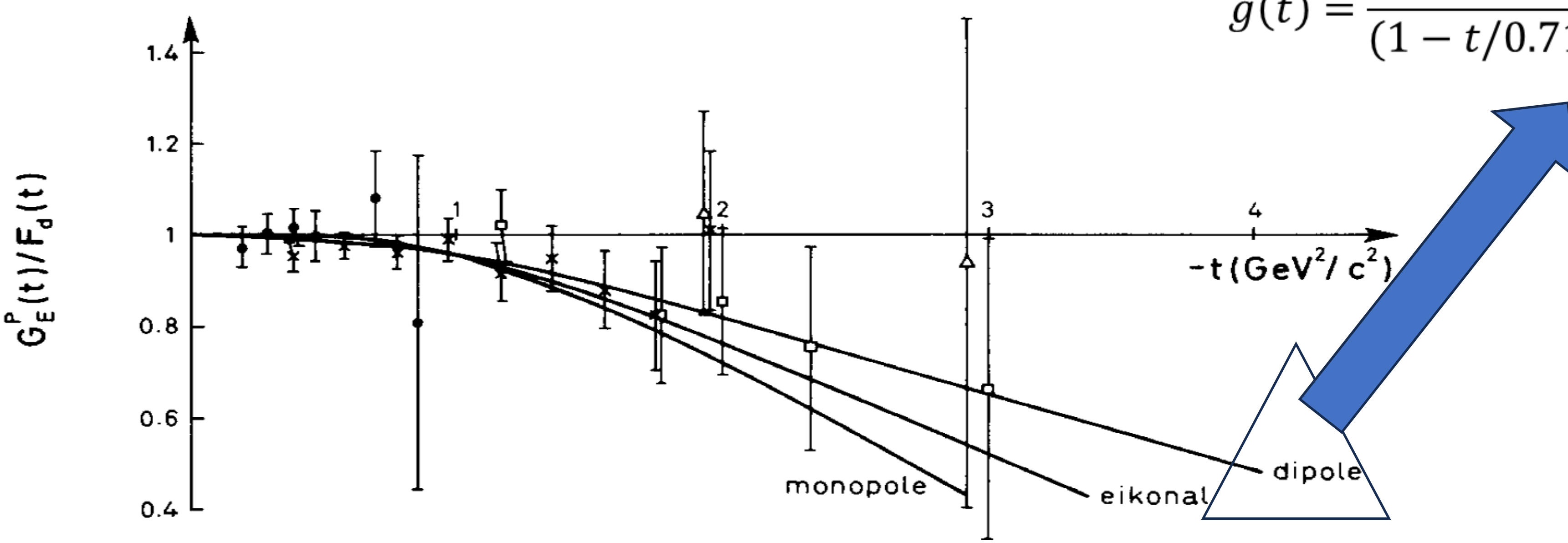
and

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.

$$g(t) = \frac{1}{(1 - t/0.71)^2}$$



EMFFs of Λ in the VMD (new proposal)

$$\mathrm{F}_1(\mathrm{Q}^2) = \mathrm{g}(\mathrm{Q}^2)[-\beta_\omega - \beta_\phi + \beta_\omega \frac{\mathrm{m}_\omega^2}{\mathrm{m}_\omega^2 + \mathrm{Q}^2} + \beta_\phi \frac{\mathrm{m}_\phi^2}{\mathrm{m}_\phi^2 + \mathrm{Q}^2} + \beta_\mathrm{x} \frac{\mathrm{m}_\mathrm{x}^2}{\mathrm{m}_\mathrm{x}^2 + \mathrm{Q}^2}]$$

$$\mathrm{F}_2(\mathrm{Q}^2) = \mathrm{g}(\mathrm{Q}^2)[(\mu_\Lambda - \alpha_\phi) \frac{\mathrm{m}_\omega^2}{\mathrm{m}_\omega^2 + \mathrm{Q}^2} + \alpha_\phi \frac{\mathrm{m}_\phi^2}{\mathrm{m}_\phi^2 + \mathrm{Q}^2} + \alpha_\mathrm{x} \frac{\mathrm{m}_\mathrm{x}^2}{\mathrm{m}_\mathrm{x}^2 + \mathrm{Q}^2}]$$

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

$$\boxed{Q^2 \to -q^2}$$

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

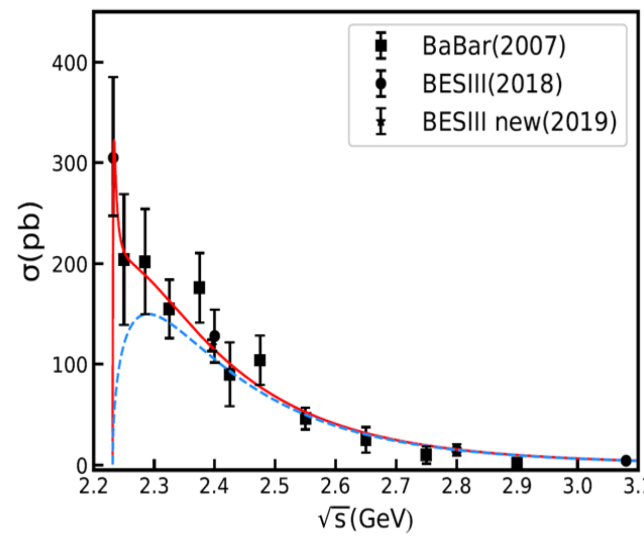
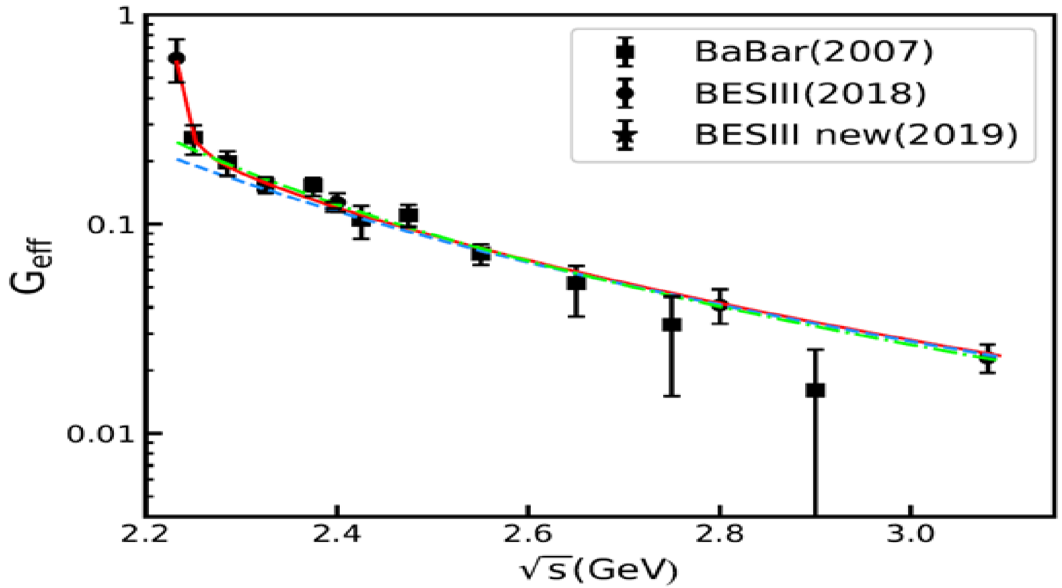


Figure: Cross section of the reaction $e^+e^- \to \bar{\Lambda}\Lambda$.



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

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

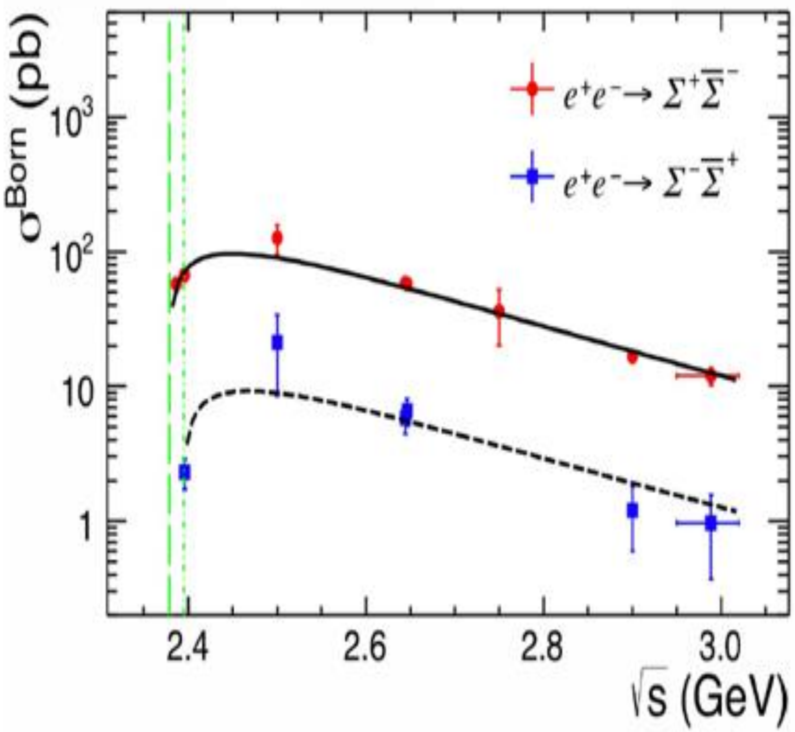
Table: Values of model parameters determined in this work.

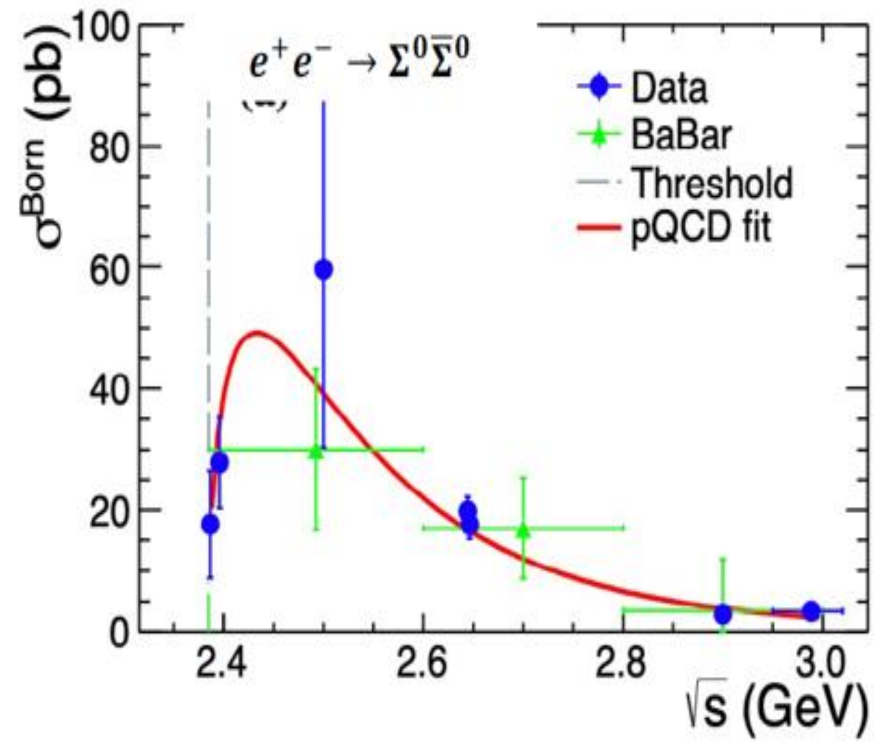
Parameter	Value	Parameter	Value
γ (GeV^{-2})	0.43	β_ω	-1.13
β_ϕ	1.35	α_ϕ	-0.40
β_x	0.0015	m_x (MeV)	2230.9
Γ_x(MeV)	4.7		

New state X(2231) ?

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

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 (VMD)

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

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

$$|\Sigma^0\bar{\Sigma}^0\rangle = -\frac{1}{\sqrt{3}}|0,0\rangle + \sqrt{\frac{2}{3}}|2,0\rangle$$

Isospin decomposition

$$F_1^{\Sigma^+} = g(q^2)(f_1^{\Sigma^+} + \frac{\beta_\rho}{\sqrt{2}}B_\rho - \frac{\beta_{\omega\phi}}{\sqrt{3}}B_{\omega\phi}),$$

$$F_2^{\Sigma^+} = g(q^2)(f_2^{\Sigma^+}B_\rho - \frac{\alpha_{\omega\phi}}{\sqrt{3}}B_{\omega\phi}),$$

$$F_1^{\Sigma^-} = g(q^2)(f_1^{\Sigma^-} - \frac{\beta_\rho}{\sqrt{2}}B_\rho - \frac{\beta_{\omega\phi}}{\sqrt{3}}B_{\omega\phi}),$$

$$F_2^{\Sigma^-} = g(q^2)(f_2^{\Sigma^-}B_\rho - \frac{\alpha_{\omega\phi}}{\sqrt{3}}B_{\omega\phi}),$$

$$F_1^{\Sigma^0} = g(q^2)(\frac{\beta_{\omega\phi}}{\sqrt{3}} - \frac{\beta_{\omega\phi}}{\sqrt{3}}B_{\omega\phi}),$$

$$F_2^{\Sigma^0} = g(q^2)\mu_{\Sigma^0}B_{\omega\phi},$$

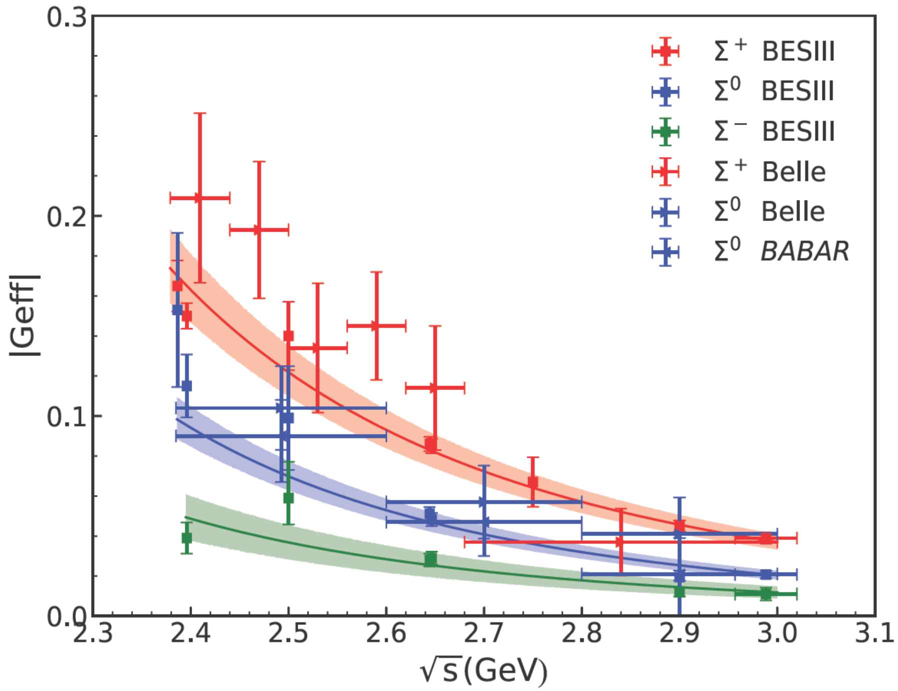
$$B_\rho = \frac{m_\rho^2}{m_\rho^2 - q^2 - im_\rho\Gamma_\rho},$$

$$B_{\omega\phi} = \frac{m_{\omega\phi}^2}{m_{\omega\phi}^2 - q^2 - im_{\omega\phi}\Gamma_{\omega\phi}},$$

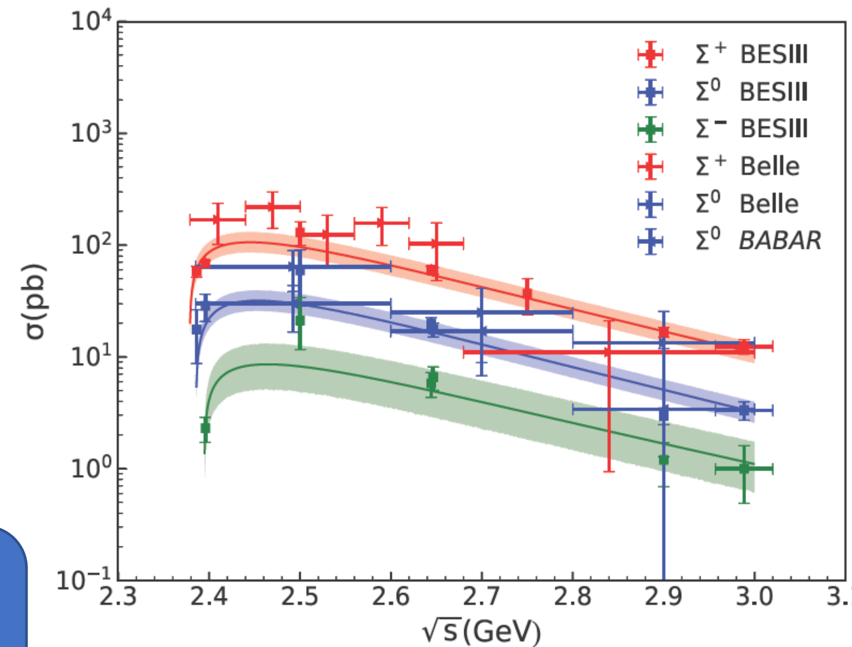
$$f_1^{\Sigma^+} = 1 - \frac{\beta_\rho}{\sqrt{2}} + \frac{\beta_{\omega\phi}}{\sqrt{3}}, \quad f_2^{\Sigma^+} = 2.112 + \frac{\alpha_{\omega\phi}}{\sqrt{3}},$$

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

EMFFs of Σ^+, Σ^-, and Σ^0 : 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 Ju-Jun Xie, **Phys. Rev. D107, 076008 (2023).**

New experimental results

PHYSICAL REVIEW LETTERS **132,** 081904 (2024)

Determination of the Σ^+ Timelike Electromagnetic Form Factors

M. Ablikim *et al.**
(BESIII Collaboration)

TABLE I. Fit results for α, $\Delta\Phi(^\circ)$, $\sin(\Delta\Phi)$, and $|G_E/G_M|$ at each energy point.

$\sqrt{s}$ (GeV)	2.3960	2.6454	2.9000
α	$-0.47 \pm 0.18 \pm 0.09$	$0.41 \pm 0.12 \pm 0.06$	$0.35 \pm 0.17 \pm 0.15$
$\Delta\Phi(^\circ)$	$-42 \pm 22 \pm 14$ $(-138 \pm 22 \pm 14)$	$55 \pm 19 \pm 14$	$78 \pm 22 \pm 9$
$\sin\Delta\Phi$	$-0.67 \pm 0.29 \pm 0.18$		
$\|G_E/G_M\|$	$1.69 \pm 0.38 \pm 0.20$	$0.72 \pm 0.11 \pm 0.06$	$0.85 \pm 0.16 \pm 0.15$

PHYSICAL REVIEW D **109,** 034029 (2024)

Measurements of Σ electromagnetic form factors in the timelike region using the untagged initial-state radiation technique

TABLE III. The cross sections ($\sigma_{\Sigma^+\bar{\Sigma}^-}$) and the effective FFs ($|G_{\mathrm{eff}}|$) for the process $e^+e^- \to \Sigma^+\bar{\Sigma}^-$ at all datasets. N^{sig} is the total number of signal events. $\bar{\varepsilon}$ is the average detection efficiency of all datasets weighted by the effective ISR luminosity. $\mathcal{L}_{\mathrm{eff}}$ is the total effective ISR luminosity. For $\sigma_{\Sigma^+\bar{\Sigma}^-}$ and $|G_{\mathrm{eff}}|$, the first and second uncertainties are statistical and systematic, respectively; for N^{sig}, the uncertainties are statistical only. The values in brackets for N^{sig}, $\sigma_{\Sigma^+\bar{\Sigma}^-}$ and $|G_{\mathrm{eff}}|$ correspond to the upper limits at 90% confidence level.

$M_{\Sigma^+\bar{\Sigma}^-}$ (GeV/c^2)	N^{sig}	$\bar{\varepsilon}(\%)$	$\mathcal{L}_{\mathrm{eff}}$ (pb^{-1})	$\sigma_{\Sigma^+\bar{\Sigma}^-}$ (pb)	$\|G_{\mathrm{eff}}\|(\times 10^{-2})$
2.379–2.44	$2.7^{+1.8}_{-1.9}(<6.8)$	0.91	15.13	$74^{+50}_{-52} \pm 5(<190)$	$14.1^{+4.8}_{-5.0} \pm 0.5(<22.7)$
2.44–2.50	16 ± 4	2.07	15.77	$190 \pm 50 \pm 20$	$18.2 \pm 2.4 \pm 1.0$
2.50–2.56	30 ± 6	3.69	16.82	$187 \pm 37 \pm 19$	$16.6 \pm 1.7 \pm 0.8$
2.56–2.62	28 ± 6	5.33	17.96	$112 \pm 24 \pm 11$	$12.3 \pm 1.3 \pm 0.6$
2.62–2.68	26 ± 6	6.49	19.22	$79 \pm 18 \pm 8$	$10.2 \pm 1.2 \pm 0.5$
2.68–2.74	20 ± 5	7.24	20.62	$52 \pm 14 \pm 4$	$8.1 \pm 1.1 \pm 0.3$
2.74–2.80	16 ± 5	7.85	22.16	$36 \pm 10 \pm 3$	$6.7 \pm 1.0 \pm 0.3$
2.80–2.86	13 ± 4	8.19	23.90	$26 \pm 8 \pm 2$	$5.5 \pm 0.9 \pm 0.2$
2.86–2.92	19 ± 5	8.62	25.83	$33 \pm 8 \pm 2$	$6.5 \pm 0.8 \pm 0.2$
2.92–2.98	$-0.7^{+4.5}_{-4.6}(<7.7)$	8.96	28.01	$-1.1^{+6.8}_{-7.1} \pm 0.1(<11.7)$	$-1.2^{+3.6}_{-3.8} \pm 0.1(<3.9)$
2.98–3.04	11 ± 6	9.23	30.50	$15 \pm 8 \pm 1$	$4.4 \pm 1.1 \pm 0.1$

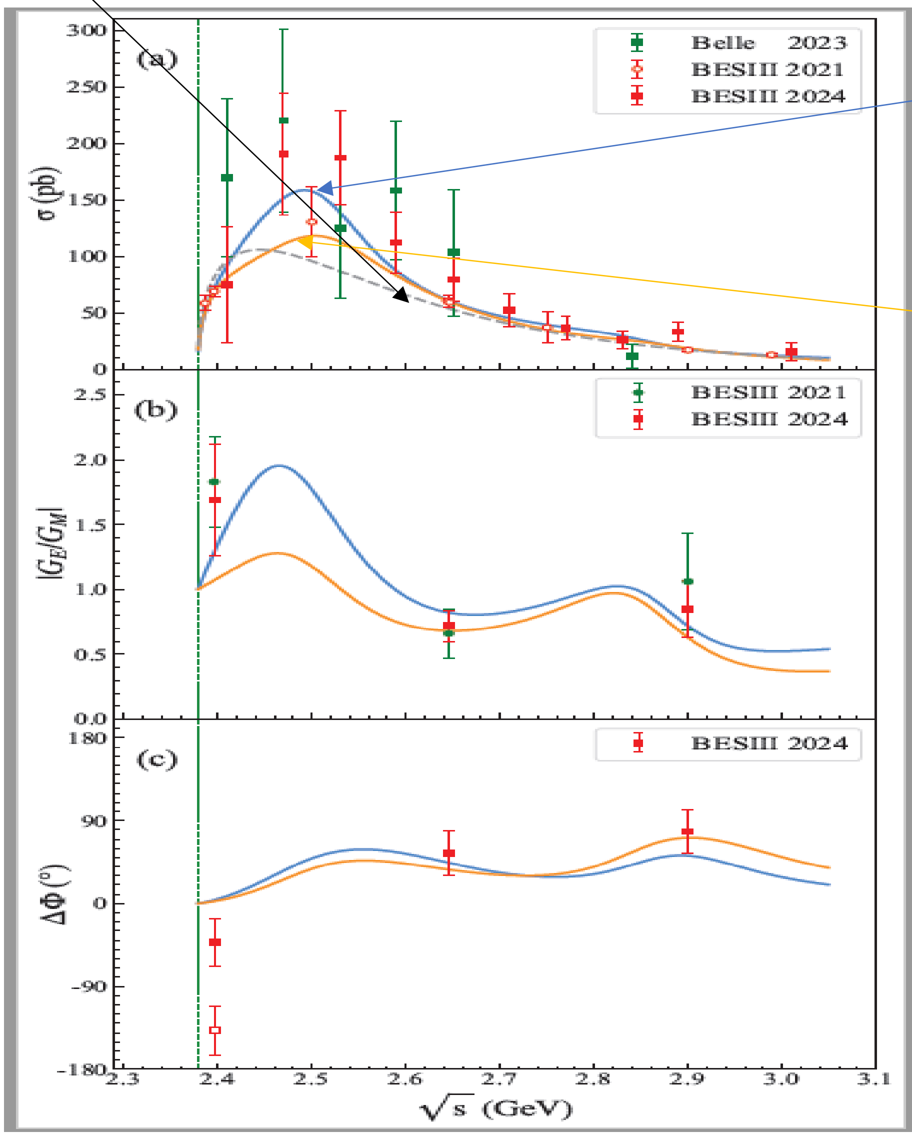
New theoretical results

Chinese Physics Letters **42**, 120201 (2025)

The Electromagnetic Form Factors of Σ and $\Sigma^0 \to \Lambda$ Transition in the Timelike Region

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

Our previous work.



Including $\omega(3D)$ *with* $M = 2300$ MeV *and* $\Gamma = 100$ MeV.

Including $\rho(3D)$ *with* $M = 2300$ MeV *and* $\Gamma = 160$ MeV.

PHYSICAL REVIEW D **104,** 054045 (2021)

Deciphering the light vector meson contribution to the cross sections of e^+e^- annihilations into the open-strange channels through a combined analysis

Jun-Zhang Wang,[1,2,‡] Li-Ming Wang,[3,†] Xiang Liu,[1,2,4,*] and Takayuki Matsuki[5,§]
[1]*School of Physical Science and Technology, Lanzhou University, Lanzhou 730000, China*
[2]*Research Center for Hadron and CSR Physics, Lanzhou University and Institute of Modern Physics of CAS, Lanzhou 730000, China*
[3]*Key Laboratory for Microstructural Material Physics of Hebei Province, School of Science, Yanshan University, Qinhuangdao 066004, China*
[4]*Lanzhou Center for Theoretical Physics, Key Laboratory of Theoretical Physics of Gansu Province, and Frontiers Science Center for Rare Isotopes, Lanzhou University, Lanzhou 730000, China*
[5]*Tokyo Kasei University, 1-18-1 Kaga, Itabashi, Tokyo 173-8602, Japan*

(Received 29 June 2021; accepted 7 September 2021; published 28 September 2021)

EMFFs of Ξ^- and Ξ^0 : Numerical results

$$|\Xi^0\bar{\Xi}^0\rangle = \frac{1}{\sqrt{2}}|1,0\rangle + \frac{1}{\sqrt{2}}|0,0\rangle, \quad |\Xi^-\bar{\Xi}^+\rangle = \frac{1}{\sqrt{2}}|1,0\rangle - \frac{1}{\sqrt{2}}|0,0\rangle$$

$$F_1^{\Xi^0} = g(q^2)\left(f_1^{\Xi^0} + \frac{\beta_\rho}{\sqrt{2}}B_\rho + \frac{\beta_{V_1}}{\sqrt{2}}B_{V_1} + \frac{\beta_{V_2}}{\sqrt{2}}B_{V_2} + \frac{\beta_{\omega\phi}}{\sqrt{2}}B_{\omega\phi}\right)$$

$$F_2^{\Xi^0} = g(q^2)\left(f_2^{\Xi^0}B_\rho + \frac{\alpha_{V_1}}{\sqrt{2}}B_{V_1} + \frac{\alpha_{V_2}}{\sqrt{2}}B_{V_2} + \frac{\alpha_{\omega\phi}}{\sqrt{2}}B_{\omega\phi}\right)$$

$$F_1^{\Xi^-} = g(q^2)\left(f_1^{\Xi^-} - \frac{\beta_\rho}{\sqrt{2}}B_\rho - \frac{\beta_{V_1}}{\sqrt{2}}B_{V_1} - \frac{\beta_{V_2}}{\sqrt{2}}B_{V_2} + \frac{\beta_{\omega\phi}}{\sqrt{2}}B_{\omega\phi}\right)$$

$$F_2^{\Xi^-} = g(q^2)\left(f_2^{\Xi^-}B_\rho - \frac{\alpha_{V_1}}{\sqrt{2}}B_{V_1} - \frac{\alpha_{V_2}}{\sqrt{2}}B_{V_2} + \frac{\alpha_{\omega\phi}}{\sqrt{2}}B_{\omega\phi}\right)$$

$$m_{V_1} = 2.742 \pm 0.007\,\mathrm{GeV}$$

$$\Gamma_{V_1} = 71 \pm 28\,\mathrm{MeV}$$

MGI model

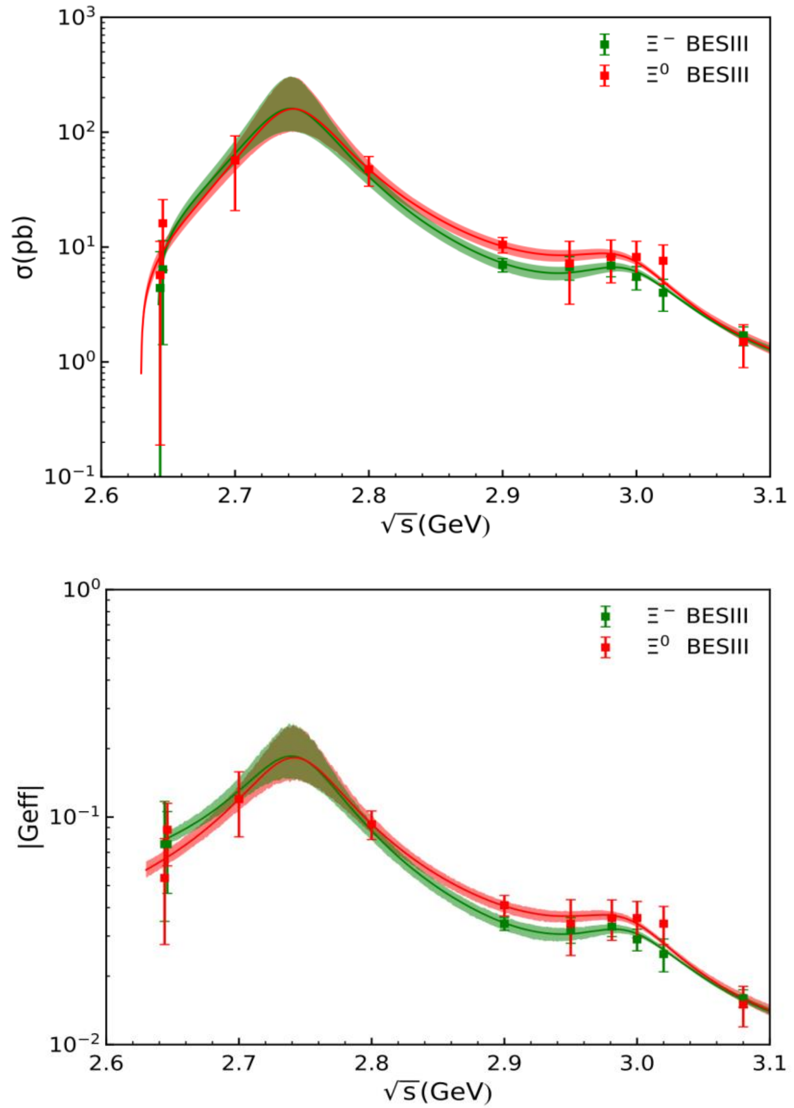
$\varphi(4D) = 2.744$ GeV

PRD.105.034011 (2022)

QCD sum rule

$m_{1^{--}}^{\Xi\bar{\Xi}} = 2.79 \pm 0.11$ GeV

PRD.105.014016 (2022)

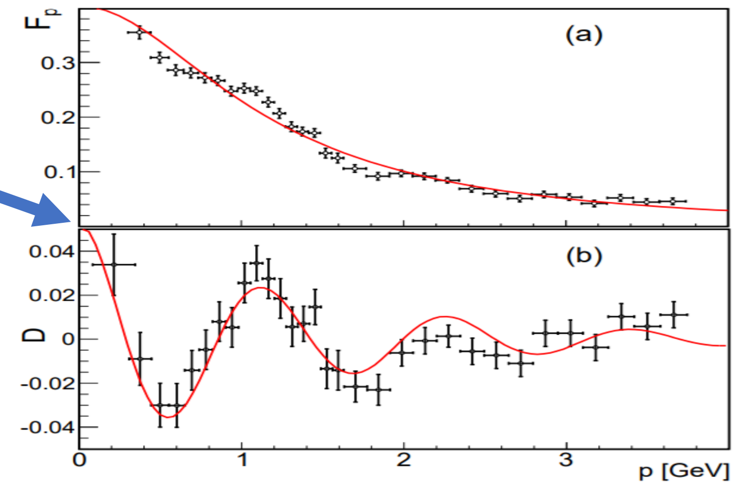


"Oscillation" of baryon effective form factors

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

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

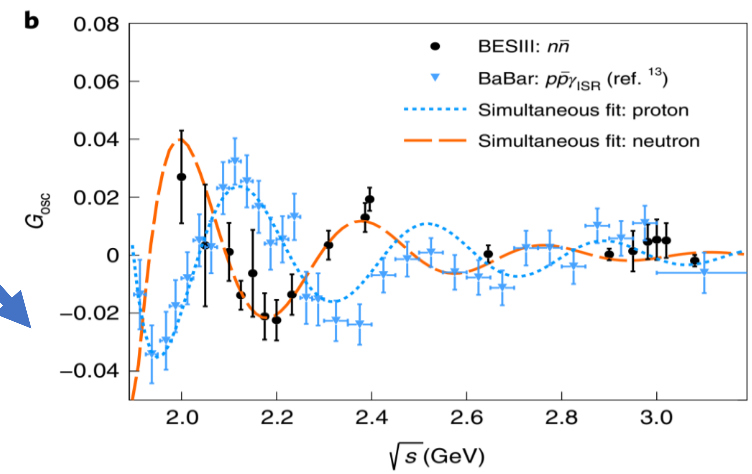
$$F_{3p}(s) = \frac{F_0}{\left(1+\frac{s}{m_a^2}\right)\left(1-\frac{s}{m_0^2}\right)^2},$$
$$F_{osc}(p(s)) = Ae^{-Bp}\cos(Cp+D).$$



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

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

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



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

重大科学目标
宇宙
反宇宙
基本对称性检验
首次发现超子衰变中电荷共轭-宇称破坏，并以最高灵敏度进行全面检验
理论预言
标准模型 ~10-5 – 10-4
新物理模型 ~10-3
STCF ~10-5
探索色禁闭之谜
首次实现夸克形成物质时间演化过程多维层析成像
在全能区建立完善的强子谱系，形成强子“元素周期表”
理论计算和实验测量的桥梁
电弱理论
微扰量子色动力学
夸克碎裂函数
粒子衰变
实验探测
物质基本结构
揭示中子内部结构振荡之谜，对核子电磁结构最精确测量
精度低
数据空白
0.08
0.06
0.04
0.02
0
−0.02
−0.04
2.0
2.2
2.4
2.6
2.8
3.0
HONOR X60 Pro

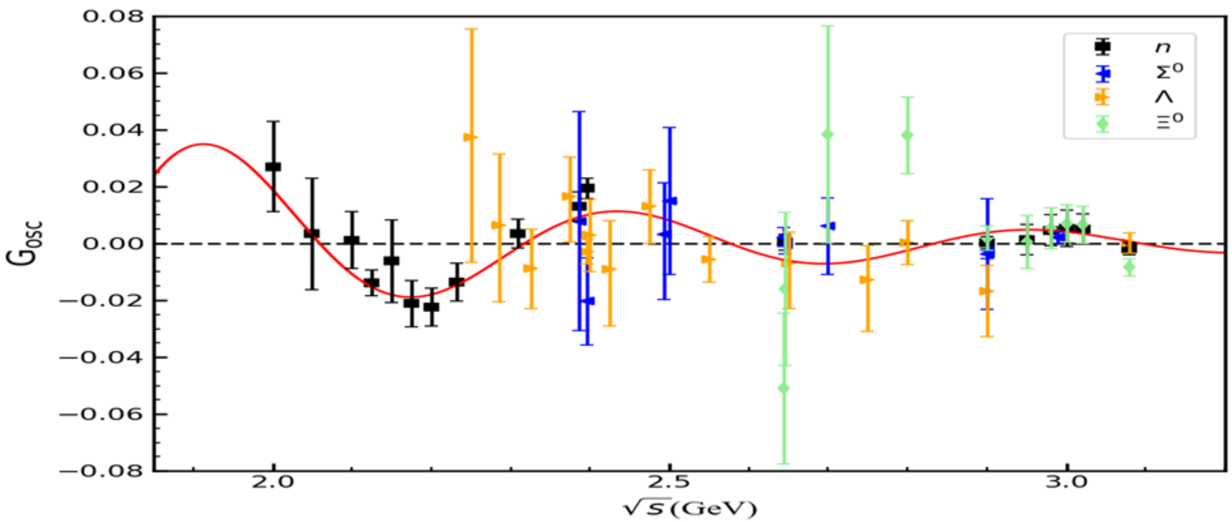
New parametrization for the "oscillation"

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

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

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

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

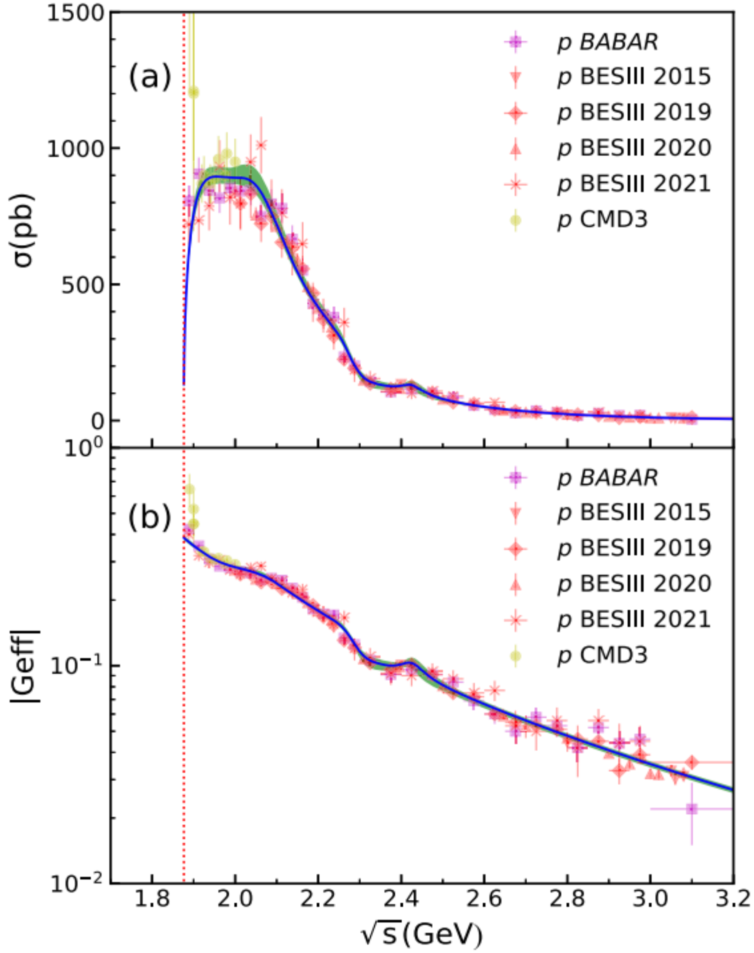


A.X. Dai, Z.Y. Li, L. Chang and Ju-Jun Xie, Chin. Phys. C 46, 073104 (2022).

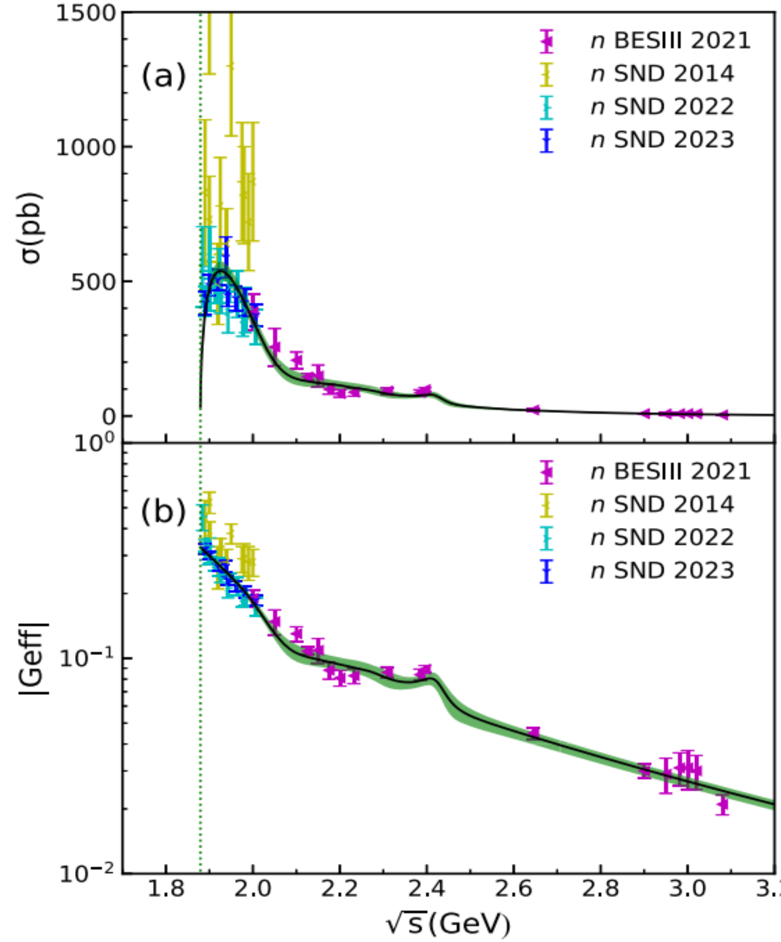
EMFFs of proton and neutron (VMD)

State	M_R (MeV)	Γ_R (MeV)
$\rho(2D)$	2040	202
$\omega(3D)$	2283	94
$\omega(5S)$	2422	64

$e^+e^- \to p\bar{p}$



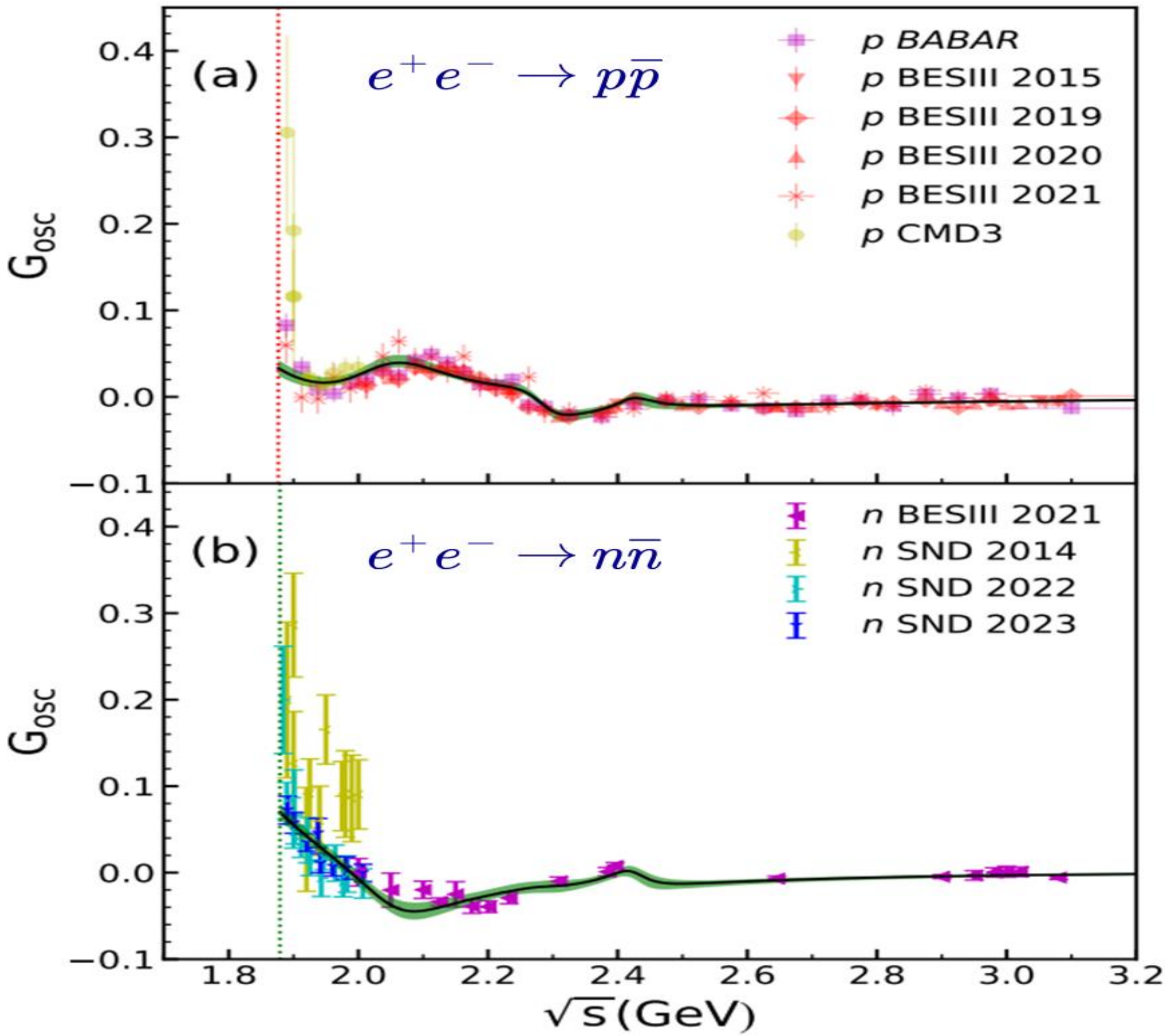
$e^+e^- \to n\bar{n}$



Bing Yan, Cheng Chen, Xia Li, Ju-Jun Xie, Phys. Rev. D109, 036003 (2024).

$$G_{\rm osc} = |G_{\rm eff}| - G_D = |G_{\rm eff}| - \frac{c_0}{(1-\gamma s)^2}$$

$$\gamma = \frac{1}{0.71}\ \mathrm{GeV}^{-2}$$

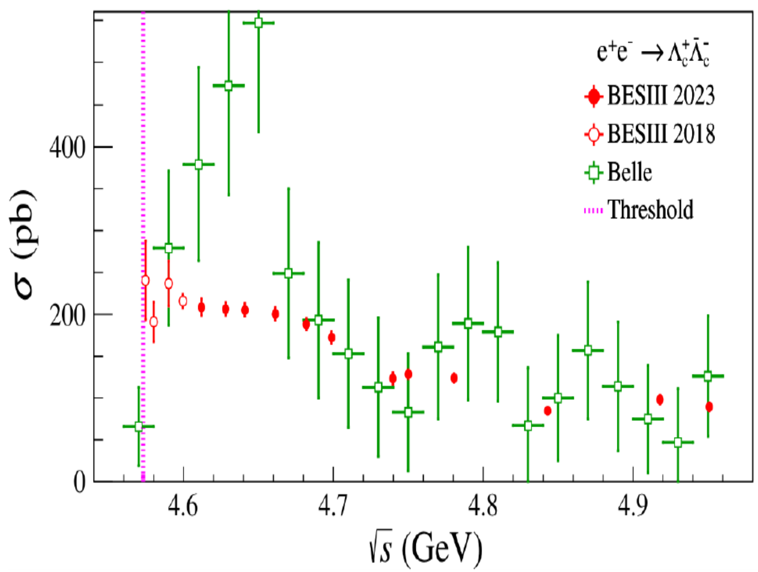


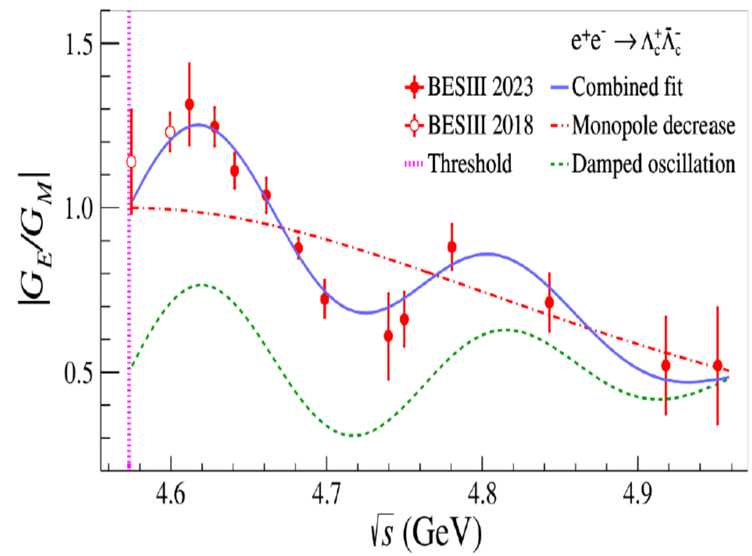
$c_0 = 5.54 \pm 0.02$ for proton

$c_0 = 4.08 \pm 0.04$ for neutron

$e^+e^- \to \Lambda_c^+\bar{\Lambda}_c^-$

PHYSICAL REVIEW LETTERS **131**, 191901 (2023)



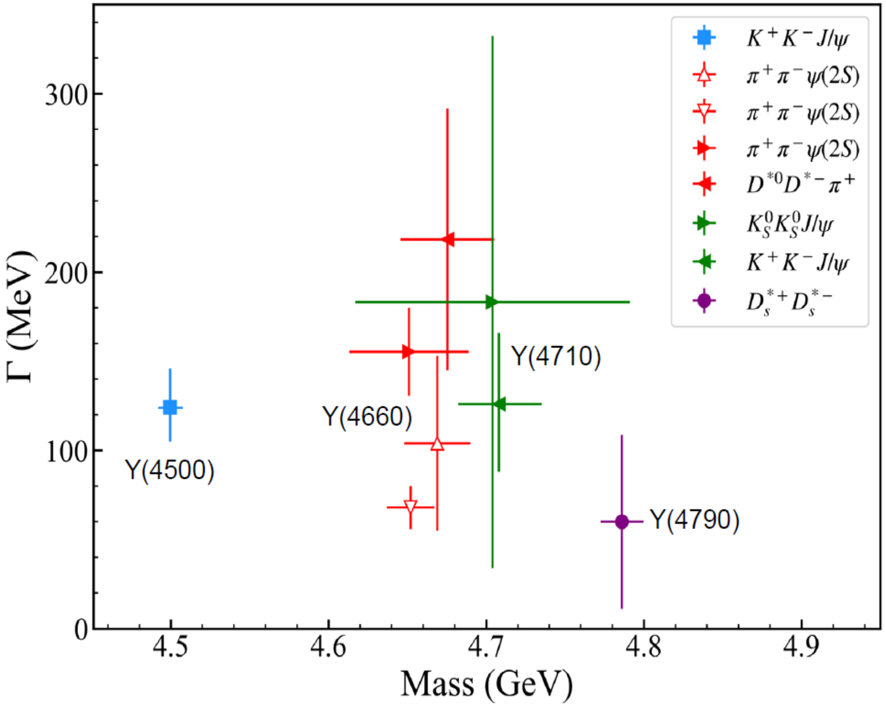


The results of BESIII revealed that there is no peak around $\sqrt{s}$ = 4.63 GeV but a long flat from the threshold to 4.68 GeV, diverging from the Belle measurements

The threshold enhancement

The long plateau figure is about 90 MeV

The oscillation behavior of the ratio



△: BABAR ▽: Belle Others: BESIII

A possible state near 4.9 GeV $\psi(4D)$

CPC.35.319 (2011); PRD.80.074001 (2009); EPL.85.61002 (2009)

Including the following charmoniumlike states:

$\psi(4500)$, $\psi(4660)$, $\psi(4790)$, $\psi(4900)$

Masses and widths of the charmoniumlike states

State	M_R (MeV)	Γ_R (MeV)
$\psi(4500)$	4500	125
$\psi(4660)$	4670	115
$\psi(4790)$	4790	100
$\psi(4900)$	4900	100

$$F_1 = g(s)\Big(f_1 + \sum_{i=1}^{4}\beta_i B_{R_i}\Big),$$

$$F_2 = g(s)\Big(f_2 B_{R_1} + \sum_{i=2}^{4}\alpha_i B_{R_i}\Big),$$

$$f_1 = 1 - \beta_1 - \beta_2 - \beta_3 - \beta_4,$$

$$f_2 = \mu_{\Lambda_c^+} - 1 - \alpha_2 - \alpha_3 - \alpha_4,$$

$$B_{R_i} = \frac{M_{R_i}^2}{M_{R_i}^2 - s - iM_{R_i}\Gamma_{R_i}}$$

$$\Gamma_{\psi(4500)} = \Gamma_0 + g_{\Lambda_c}\sqrt{\frac{s}{4} - M_{\Lambda_c^+}^2}$$

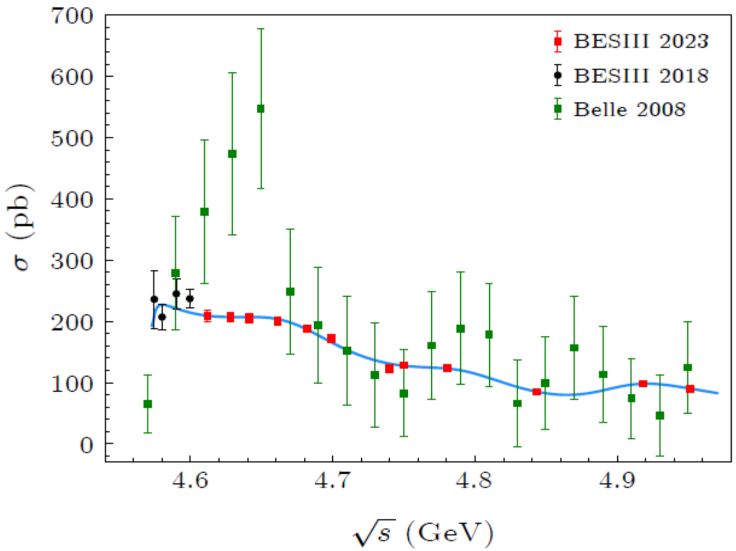
$$g(s) = \frac{1}{(1-\gamma s)^2}$$

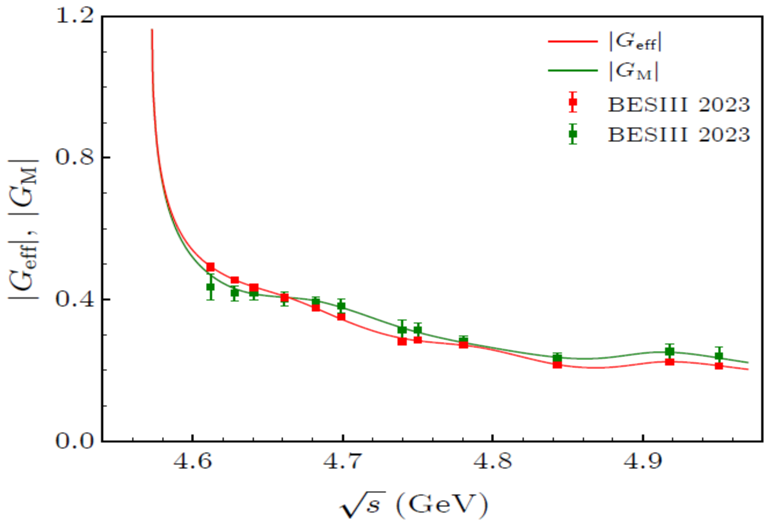
$$\gamma = 0.147 \pm 0.017\ \mathrm{GeV}^{-2}$$

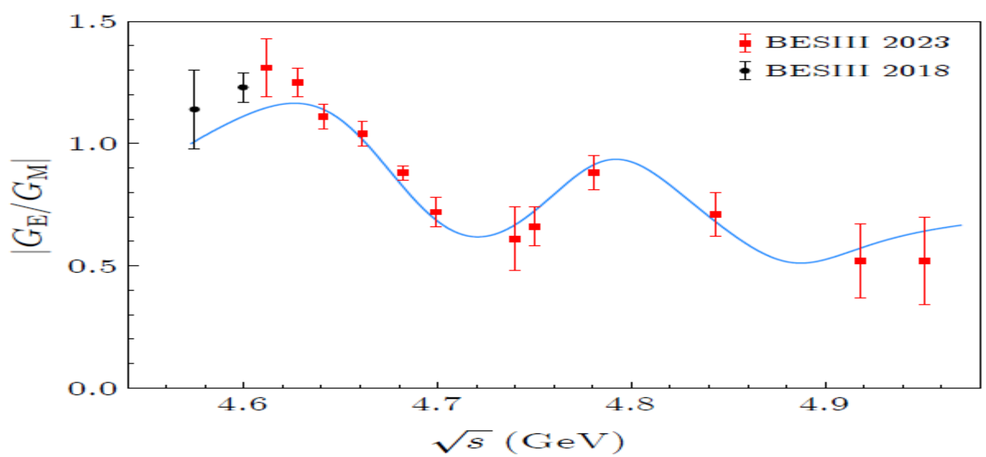
Chinese Physics Letters **41**, 021302 (2024) Express Letter

$e^+e^- \to \Lambda_c^+\bar{\Lambda}_c^-$ 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*]







Summary

1、 Threshold enhancement

a) Final state interaction

b) vector states (Flatté: strong coupling)

+ Other models

2、 "Oscillation" of baryon effective form factors

a) Phenomenology

b) **Vector excited states**

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

We conclude that

The nonmonotonic structures observed in the line shape of the $e^+e^- \to B\bar{B}$ *total cross sections can be naturally explained within the VMD model.*

The $e^+e^- \to B\bar{B}$ *reactions can be used to study the excited vector states.*

Thank you very much for your attention!