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

Ju-Jun Xie
（谢 聚 军）

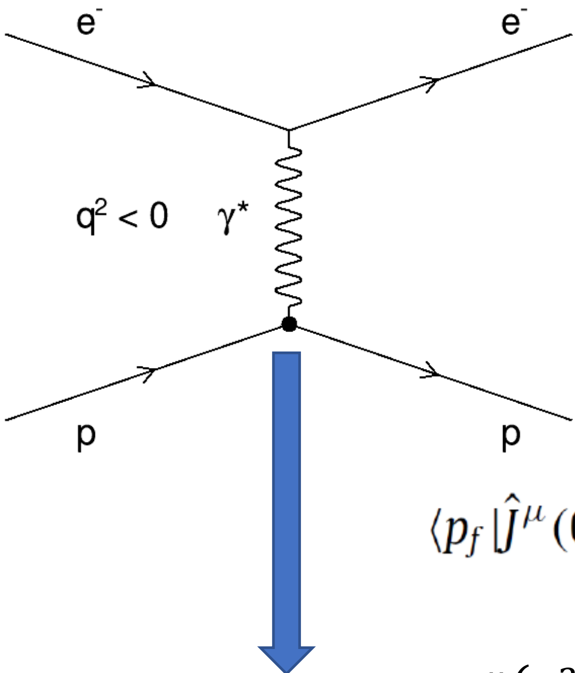
Institute of Modern Physics, Chinese Academy of Sciences
（中 国 科 学 院 近 代 物 理 研 究 所）

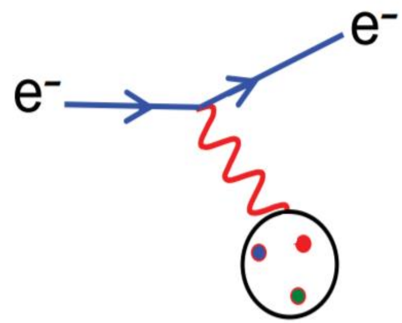
2024年10月26日@非微扰方法及其在高能物理中的应用专题研讨会
安徽 合肥 中国科学技术大学

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

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

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

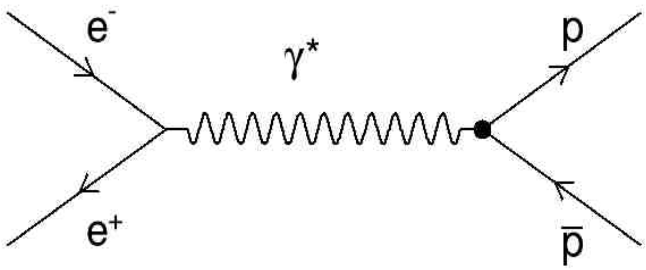
$$G_E^N(Q^2) = F_1^N(Q^2) - \tau F_2^N(Q^2)\ ,\ \ G_M^N(Q^2) = F_1^N(Q^2) + F_2^N(Q^2)\ ,\ \ \tau = \frac{Q^2}{4M_N^2}$$

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

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)

$q^2 > 0$

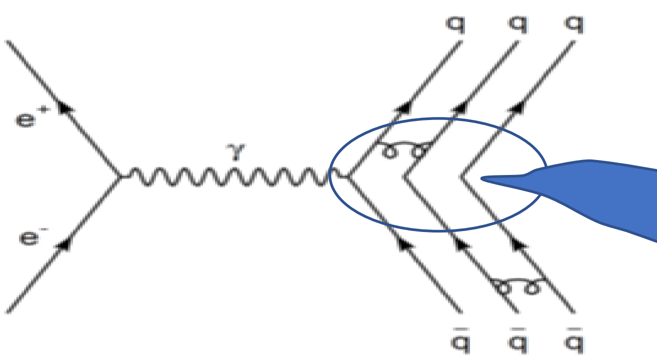


$$\left(\frac{d\sigma}{d\Omega}\right)^{th}_{e^+e^-\to N\bar{N}} = \frac{\alpha^2\beta}{4q^2} C_N(q^2)\left\{|G_M^N(q^2)|^2(1+\cos^2\theta) + |G_E^N(q^2)|^2\frac{1}{\tau}\sin^2\theta\right\}$$

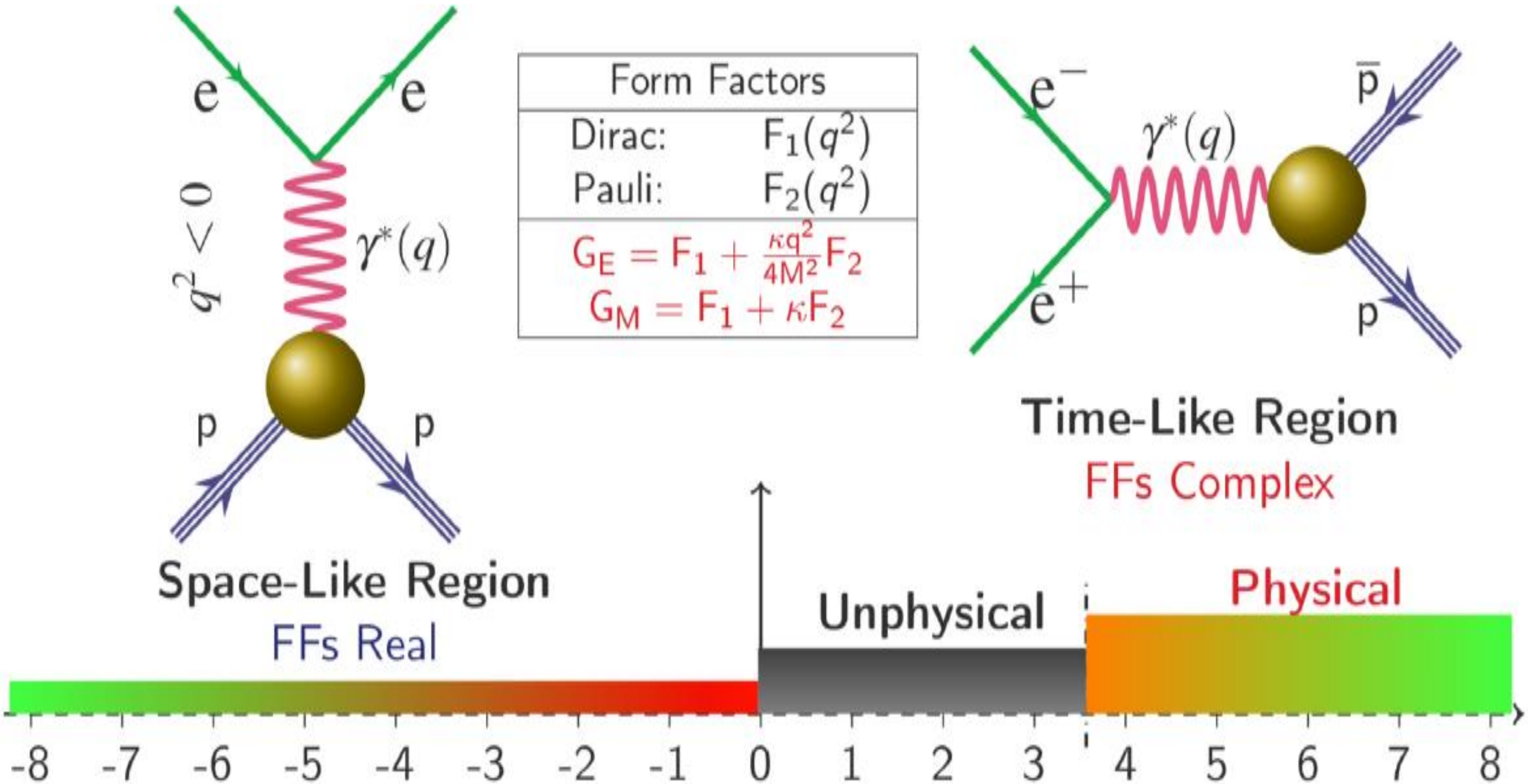
$$\sigma^{th}_{e^+e^-\to N\bar{N}} = \frac{\alpha^2\beta}{4q^2} C_N(q^2)\int d\Omega\left[|G_M^N(q^2)|^2(1+\cos^2\theta) + |G_E^N(q^2)|^2\frac{\sin^2\theta}{\tau}\right]$$

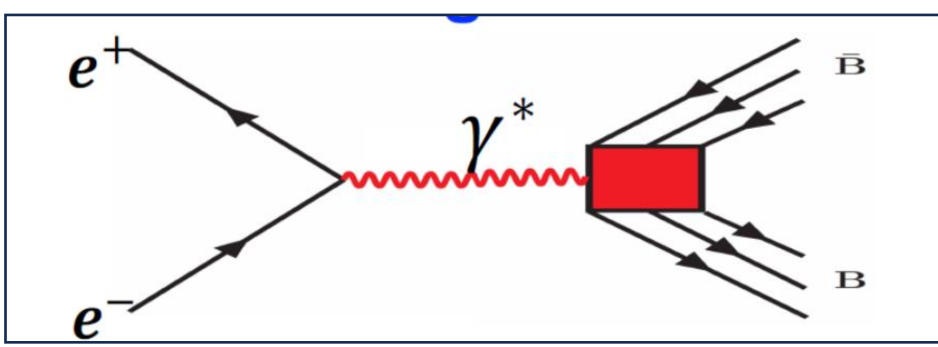
$$= \frac{4\pi\alpha^2\beta}{3q^2} C_N(q^2)\left[|G_M^N(q^2)|^2 + \frac{|G_E^N(q^2)|^2}{2\tau}\right].$$

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



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

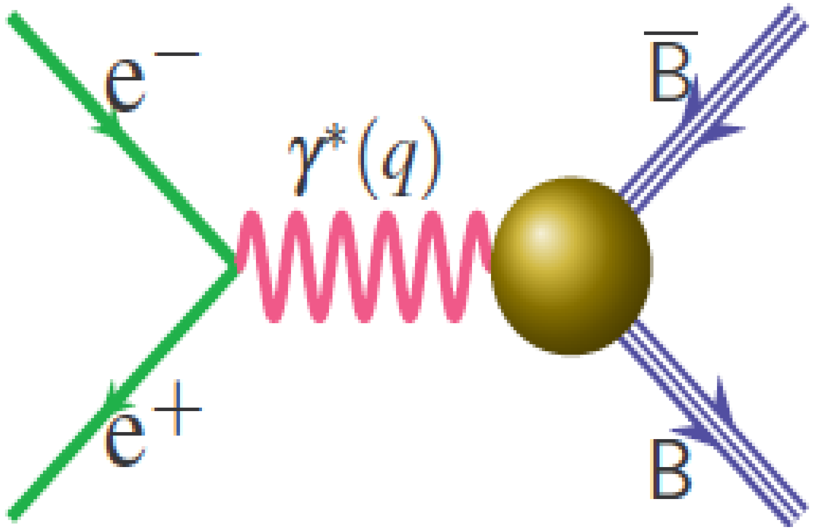


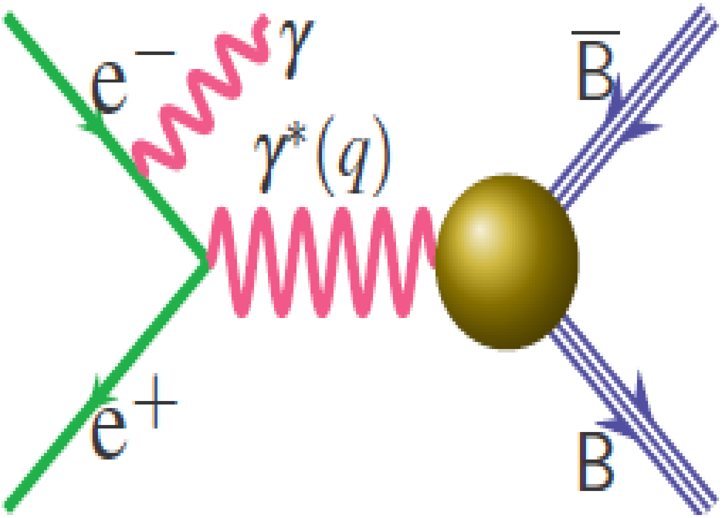


From QED to QCD

Both QED and QCD

Experimental measurements (time-like)





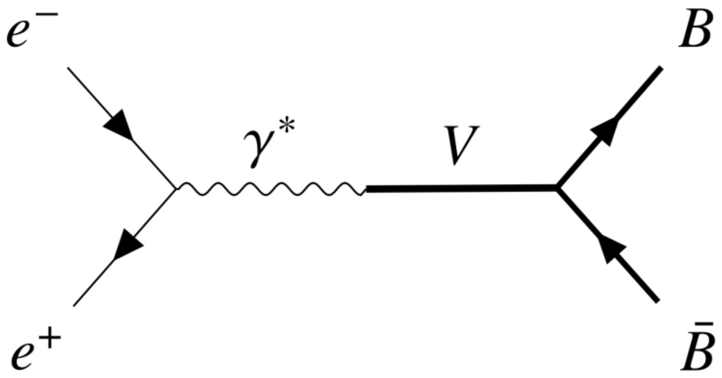
Energy Scan

Initial State Radiation

Both techniques can be used on the experimental side.

VMD: vector meson dominance model

$$\mathcal{L}_{V\gamma} = \sum_V \frac{eM_V^2}{f_V} V_\mu A^\mu \qquad \mathcal{L}_{BBV} = g_V \bar{\psi}\gamma_\mu \psi V^\mu + \frac{\kappa_V}{4M}\bar{\psi}\sigma_{\mu\nu}(\partial^\mu V^\nu - \partial^\nu V^\mu)$$



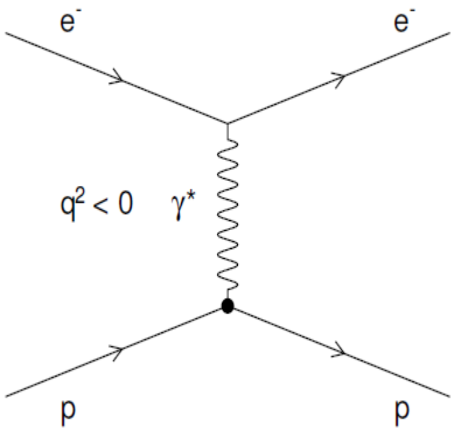
$$\Gamma_\mu^V = g_V \gamma_\mu + i\frac{\kappa_V}{2M}\sigma_{\mu\nu} q^\nu$$

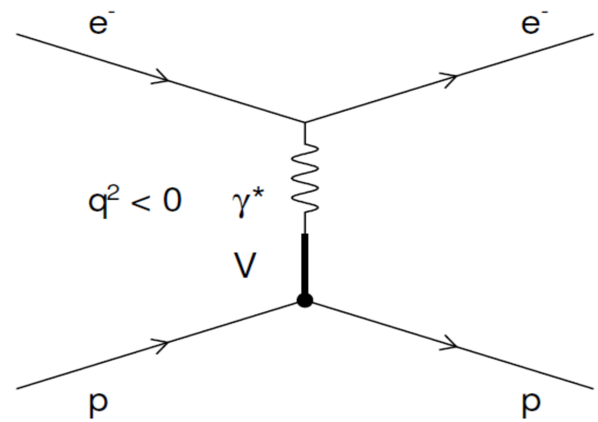
$$\Gamma_\mu = \gamma_\mu F_1(q^2) + i\frac{F_2(q^2)}{2M}\sigma_{\mu\nu}q^\nu = \frac{1}{f_V}\frac{M_V^2}{M_V^2 - q^2}\Gamma_\mu^V$$

$$F_1(q^2) = \sum_V \beta_V \frac{M_V^2}{M_V^2 - q^2}, \quad \beta_V = \frac{g_V}{f_V}$$

$$F_2(q^2) = \sum_V \alpha_V \frac{M_V^2}{M_V^2 - q^2}, \quad \alpha_V = \frac{\kappa_V}{f_V}$$

VMD for nucleon





Dirac and Pauli isoscalar and isovector form factors are

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

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

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

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

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

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

$$G_E = F_1 - \tau F_2$$

$$G_M = F_1 + F_2$$

Volume 43B, number 3 PHYSICS LETTERS 5 February 1973

SEMI-PHENOMENOLOGICAL FITS TO NUCLEON ELECTROMAGNETIC FORM FACTORS

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

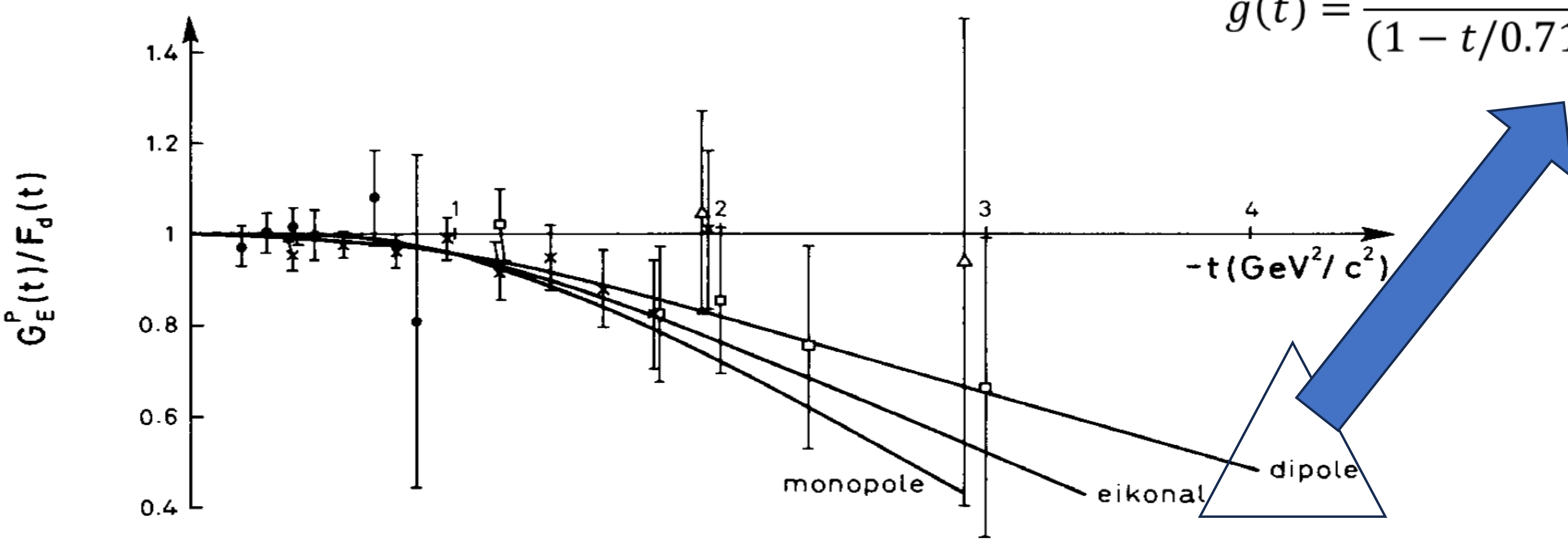
and

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

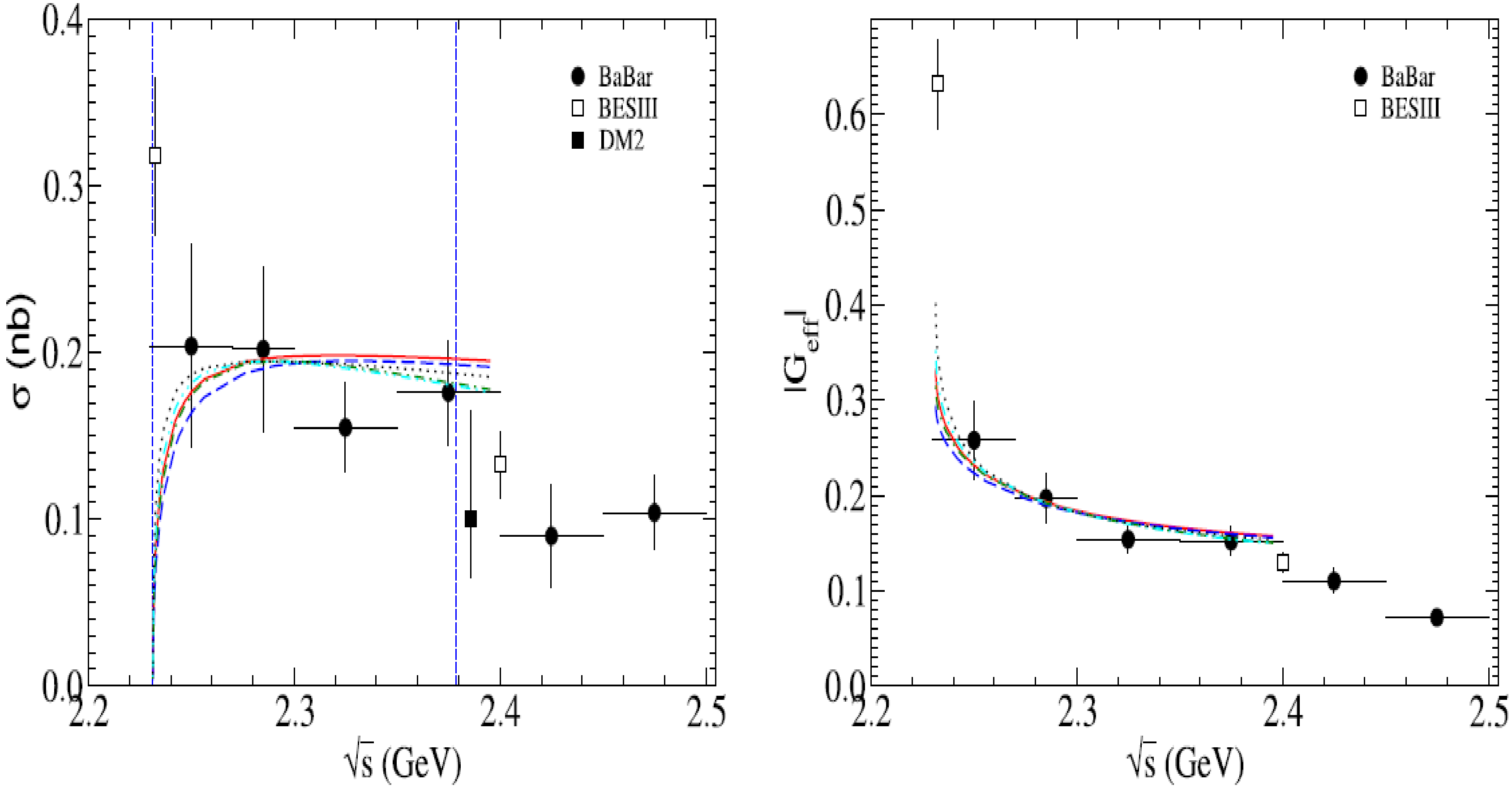
Received 31 August 1972

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.

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

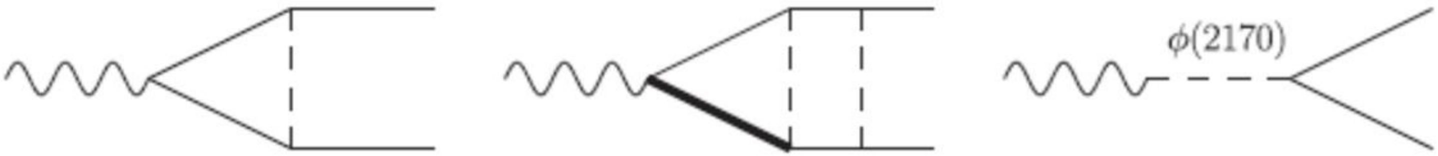


Λ



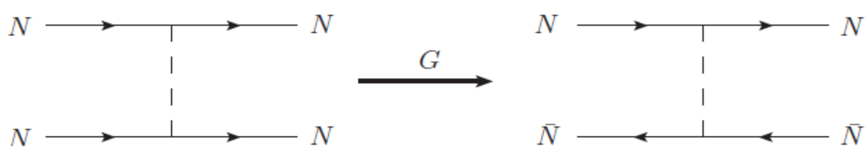
J. Haidenbauer and U. G. Meißner, Phys. Lett. B 761, 456-461(2016).

Threshold enhancement：final state interaction



(a) (b) (c)

FSI-meson exchange *N*-excitation (Δ)* *First flavorless vector meson*

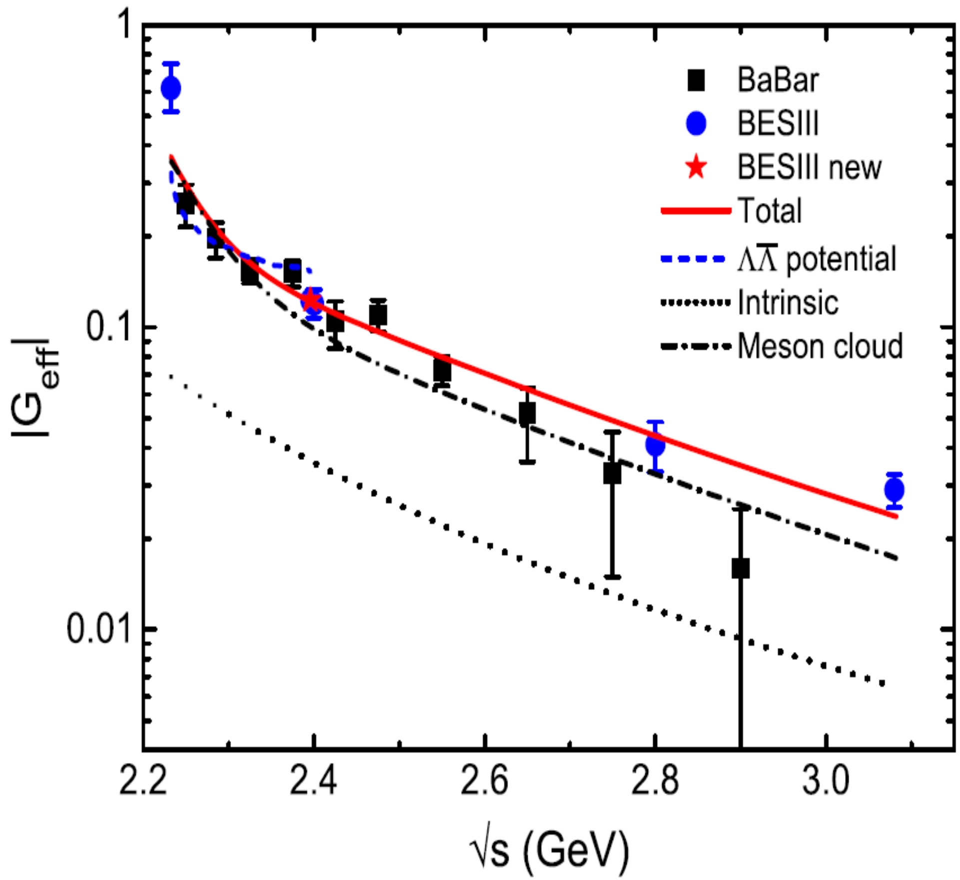


$$V_{\bar{N}N}^{\mathrm{OBE}} = (-1)^I V_{NN}^{\mathrm{OBE}}, \quad V_{\bar{N}N}^{\mathrm{TBE}} = (-1)^{I_1+I_2} V_{NN}^{\mathrm{TBE}}$$

$$T_{L''L'}(p'', p'; E_k) = V_{L''L'}(p'', p') + \sum_L \int \frac{dpp^2}{(2\pi)^3} V_{L''L}(p'', p) \frac{1}{2E_k - 2E_p + i0^+} T_{LL'}(p, p'; E_k)$$

I.T. Lorenz, H.W. Hammer and U.G. Meissner, **Phys. Rev. D92, 034018 (2015).**

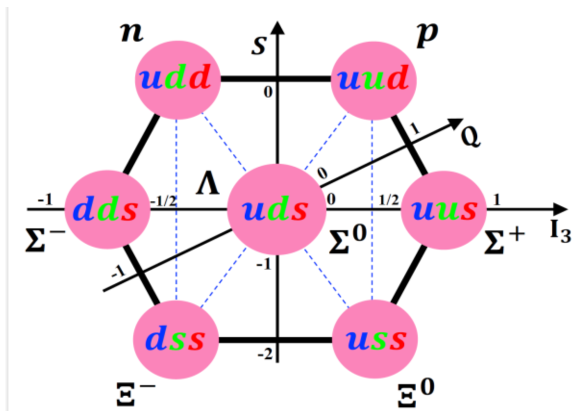
Q.H. Yang, L.Y. Dai, D. Guo, J. Haidenbauer, X.W. Kang and U.G. Meissner, arXiv:2206.01494.



fit. In the present scenario, there are 16 experimental data and 10 free parameters. The value of intrinsic parameter γ is fitted to be 0.336 GeV^{-2} and the other parameters are summarized in Table II. It should be noticed that $g(q^2)$

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

$$\gamma_N = \frac{1}{0.71\ \mathrm{GeV}^2} = 1.408\ \mathrm{GeV}^{-2}$$



State	Mass	Width	State	Mass	Width
$\omega(782)$ [55]	782	8.1	$\phi(1020)$ [56]	1019	4.2
$\omega(1420)$ [57]	1418	104	$\phi(1680)$ [57]	1674	165
$\omega(1650)$ [57]	1679	121	$\phi(2170)$ [58]	2171	128

Y. Yang, D. Y. Chen and Z. Lu,
Phys. Rev. D 100, 073007 (2019).

EMFFs of Λ in the VMD (new proposal)

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

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

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

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

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

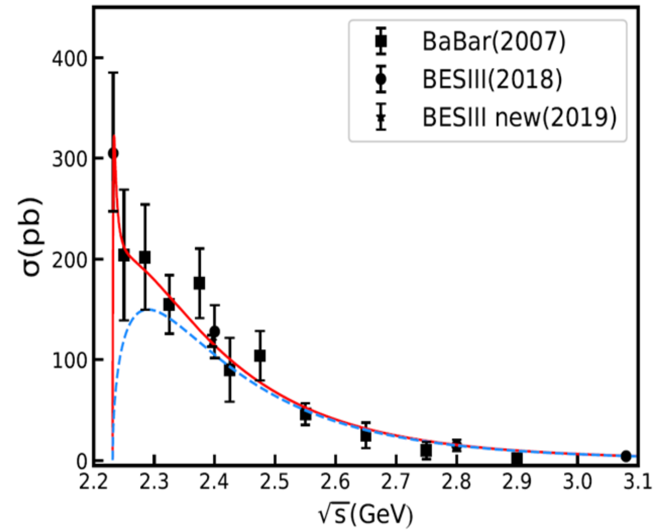
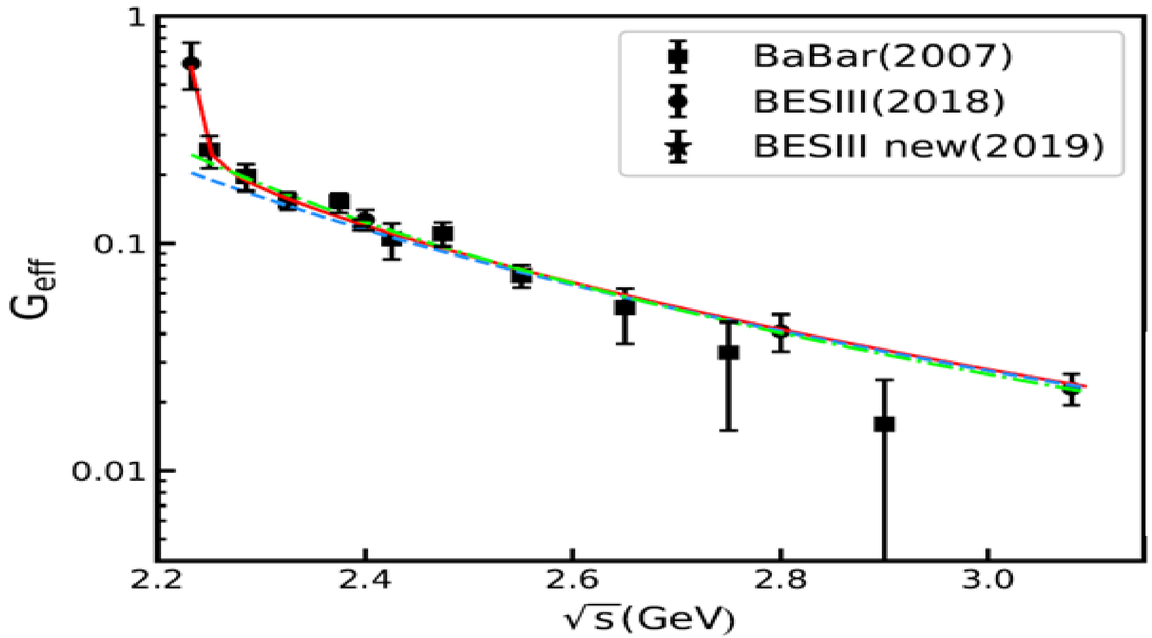


Figure: Cross section of the reaction $e^+e^- \to \bar{\Lambda}\Lambda$.

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

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

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)

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

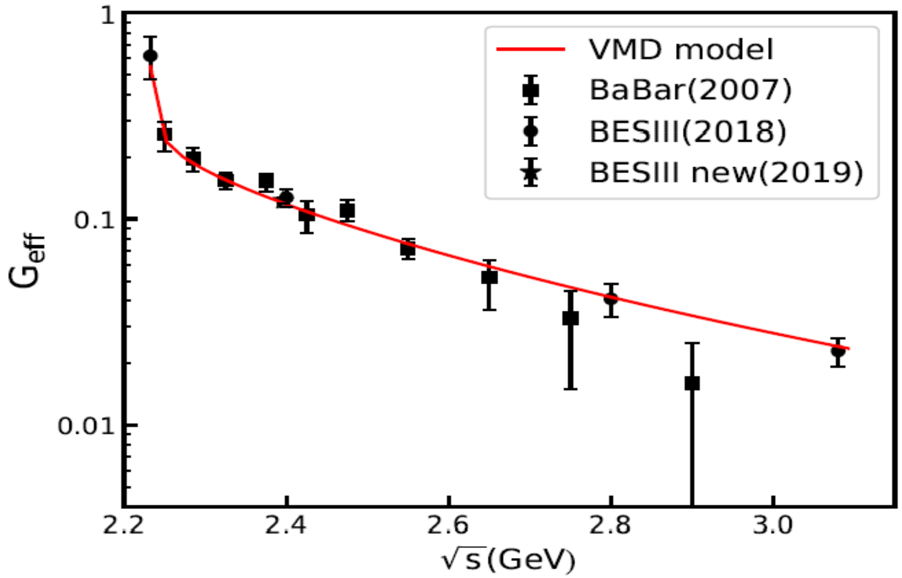


Figure: Fitting result of $|G_{eff}|$ with Flatte.

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

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

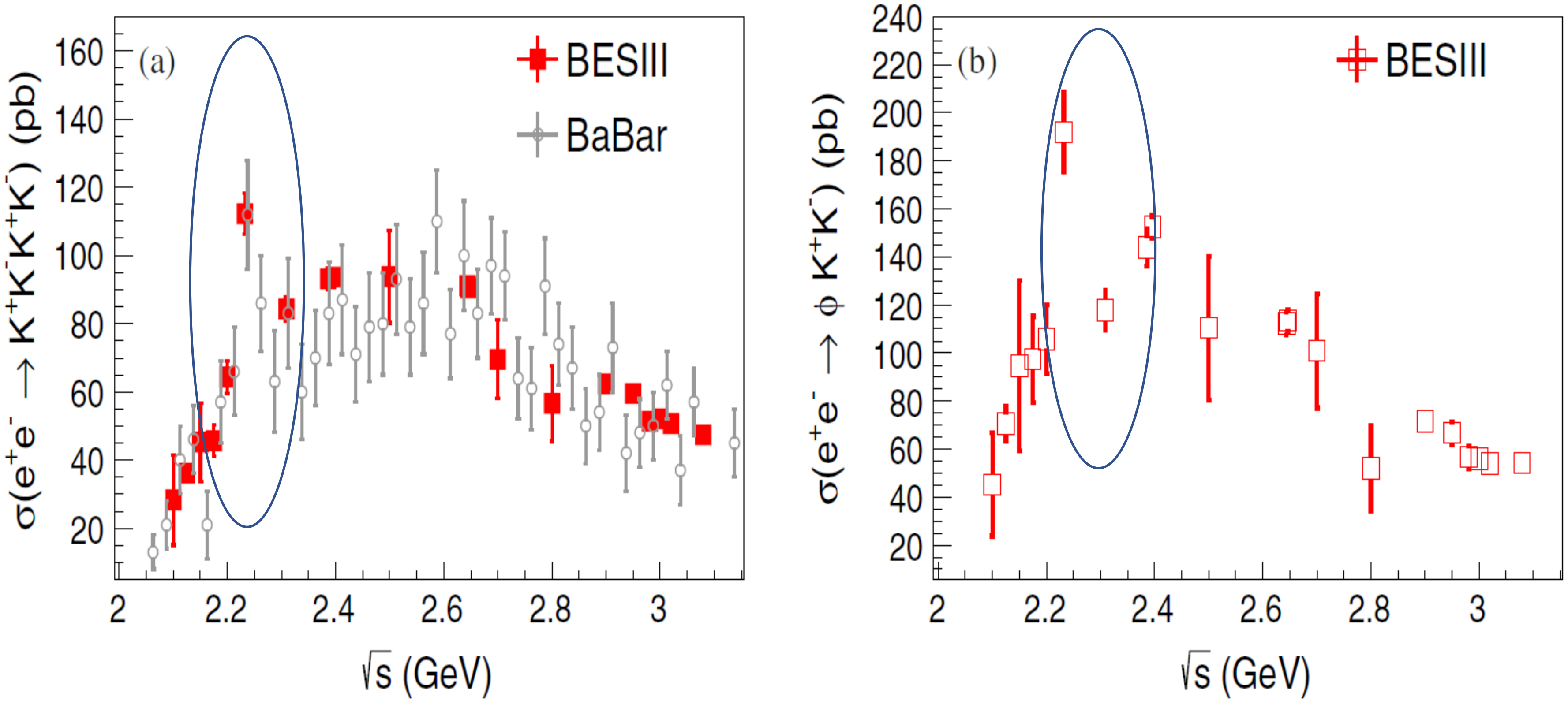
$$\Gamma_{K\bar{K}} = \begin{cases} g_K\sqrt{(1/4)m^2 - m_K^2} & \text{above threshold} \\ i g_K\sqrt{m_K^2 - (1/4)m^2} & \text{below threshold} \end{cases}$$

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

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

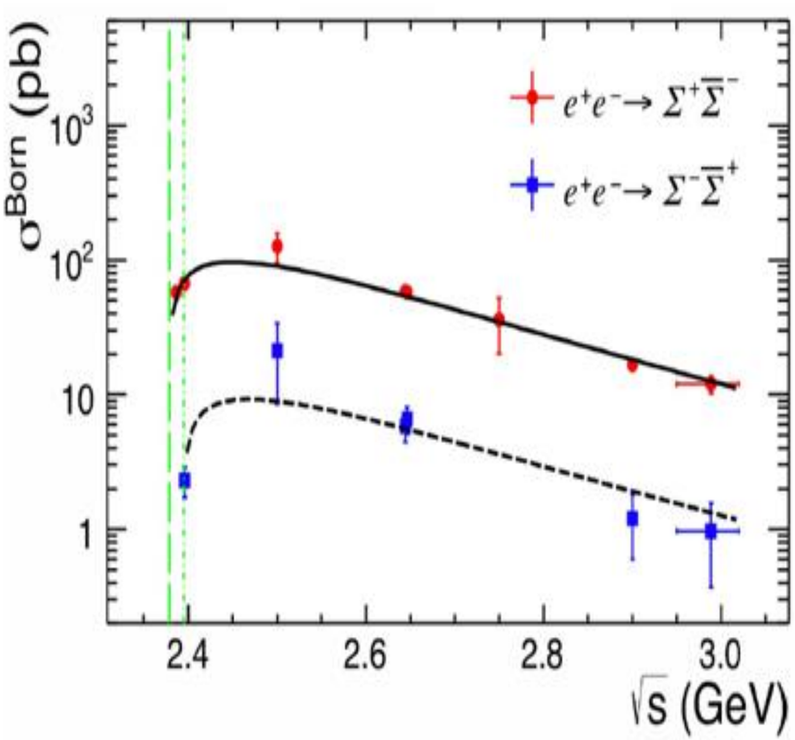
Z. Y. Li, A. X. Dai and J. J. Xie, Chin. Phys. Lett. 39, 011201 (2022).

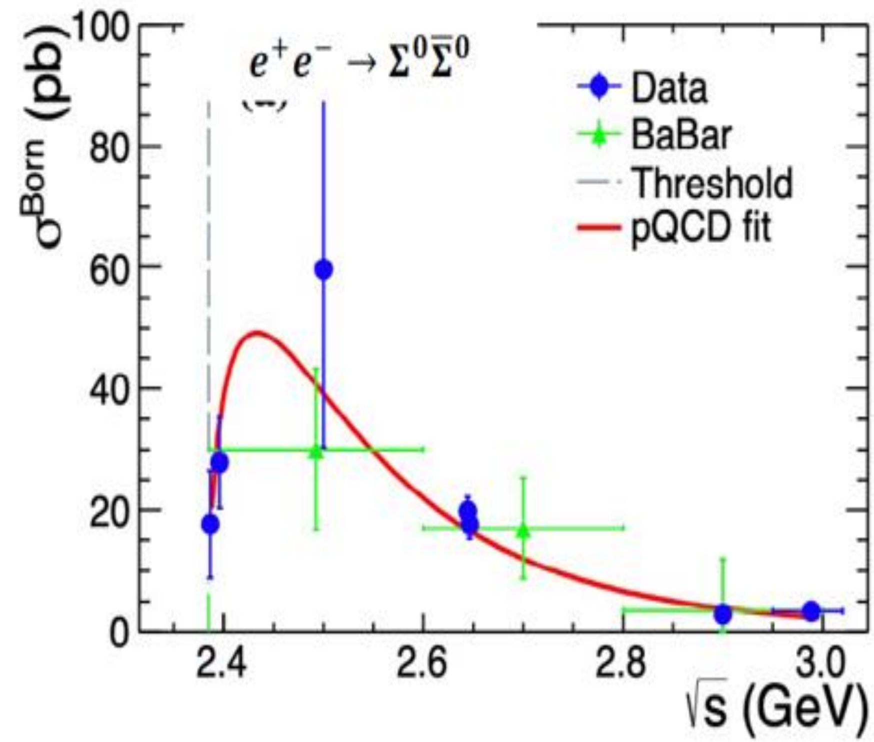
Where is the X(2231)?



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 (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

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

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

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

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

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

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

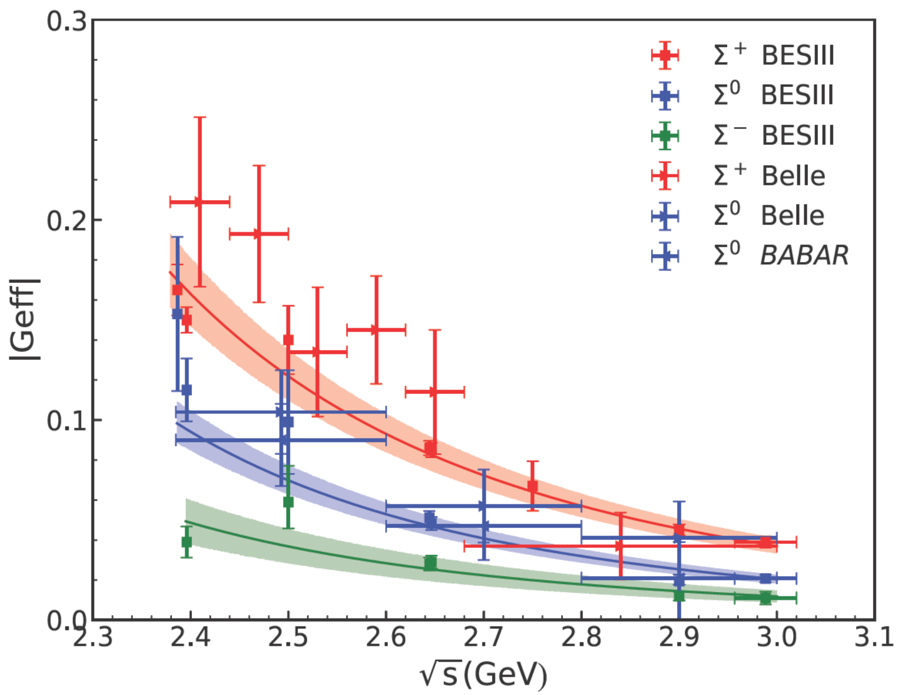
$$B_\rho = \frac{m_\rho^2}{m_\rho^2 - q^2 - im_\rho\Gamma_\rho},$$

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

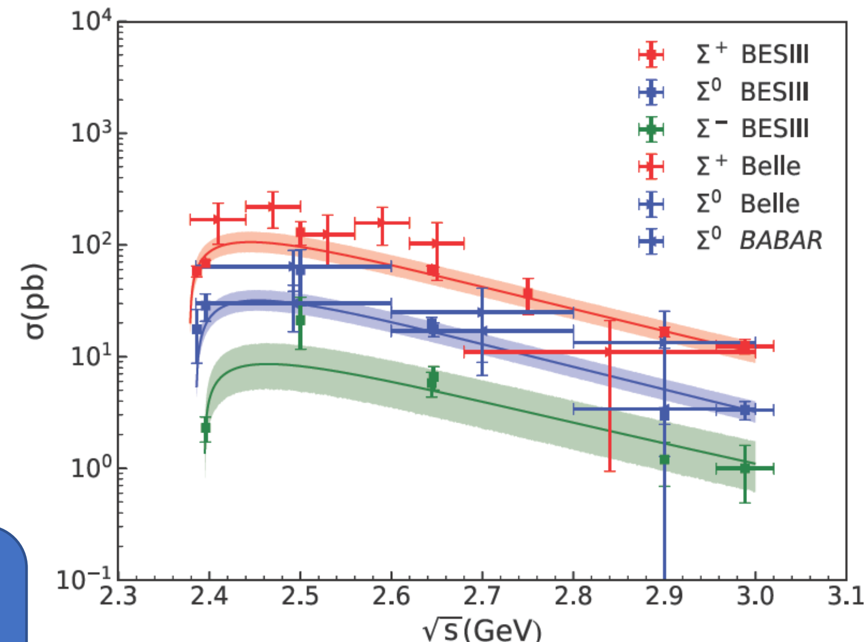
$$f_1^{\Sigma^+} = 1 - \frac{\beta_\rho}{\sqrt{2}} + \frac{\beta_{\omega\phi}}{\sqrt{3}}, \quad f_2^{\Sigma^+} = 2.112 + \frac{\alpha_{\omega\phi}}{\sqrt{3}},$$

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

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 J. J. Xie, **Phys. Rev. D107, 076008 (2023).**

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

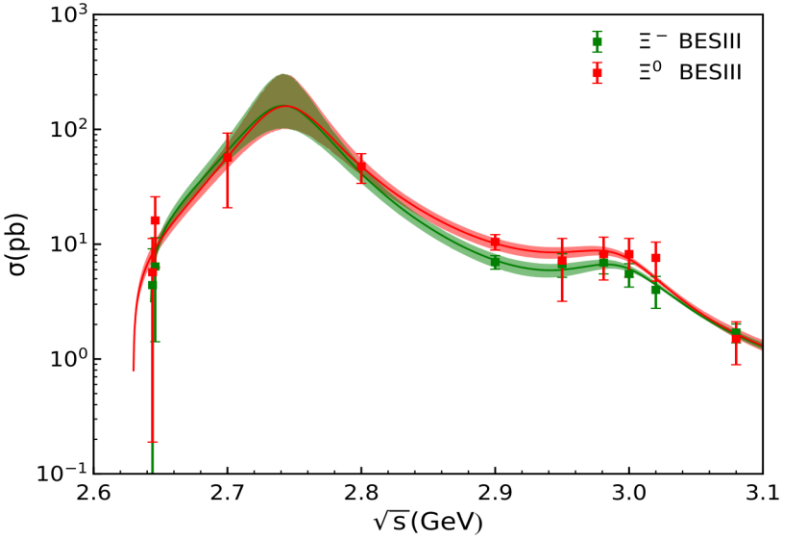
$$\varphi(4D) = 2.744\ \mathrm{GeV}$$

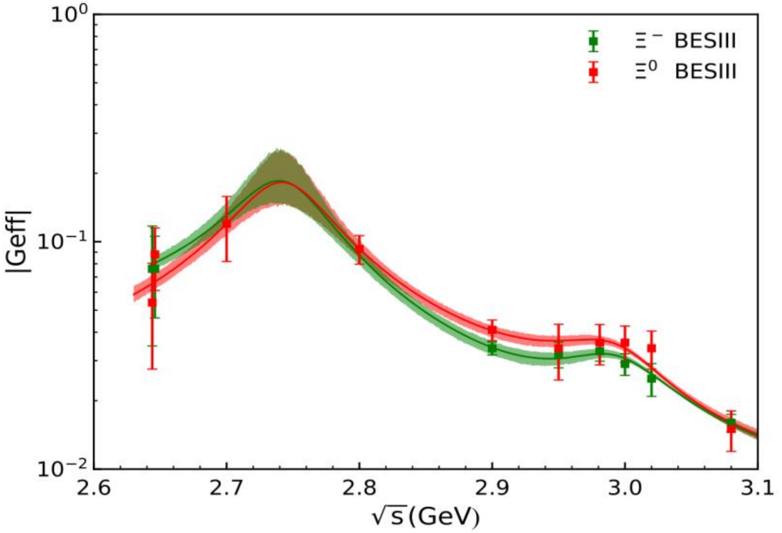
PRD.105.034011 (2022)

QCD sum rule

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

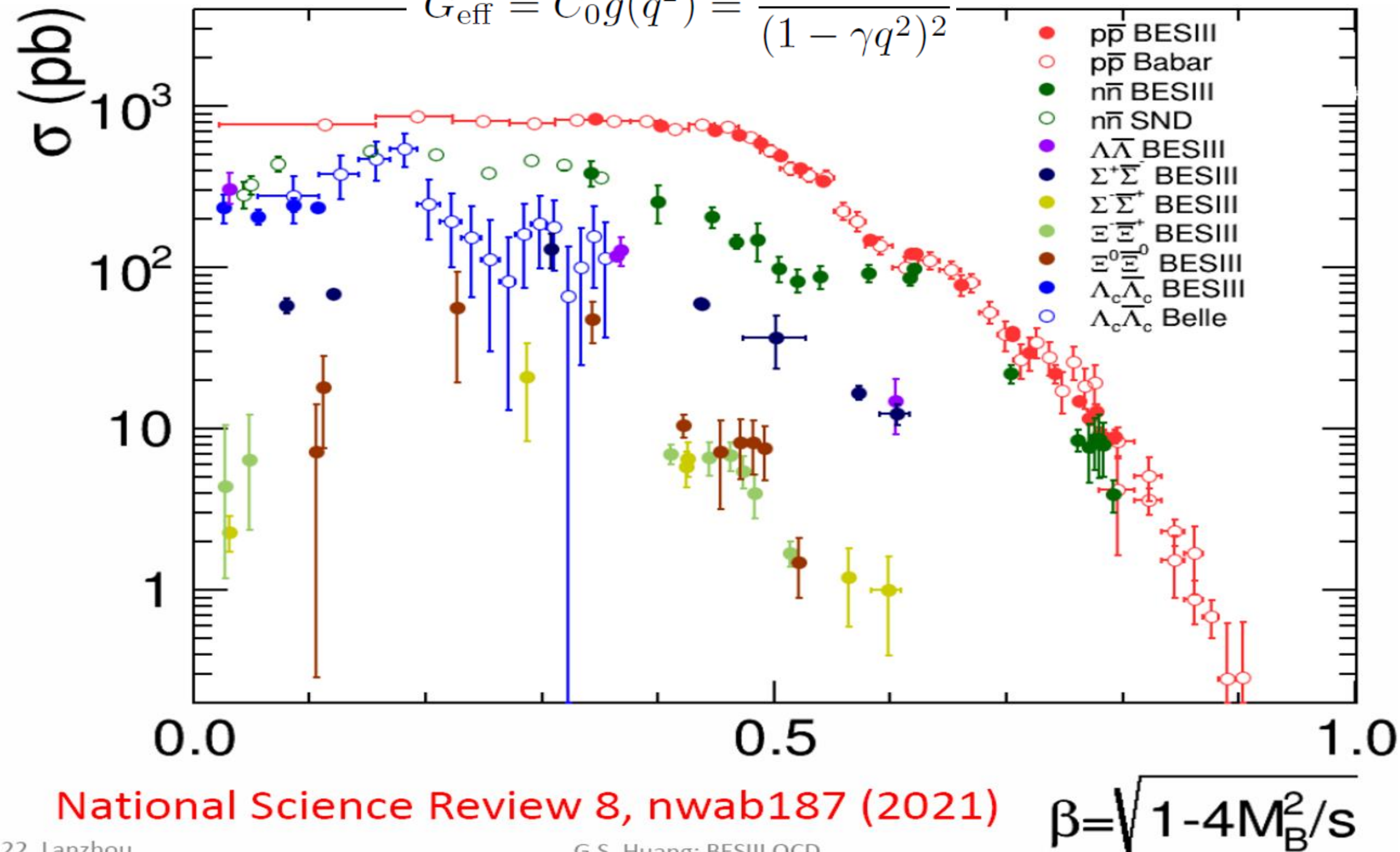
PRD.105.014016 (2022)





Dipole behavior of baryon effective form factors

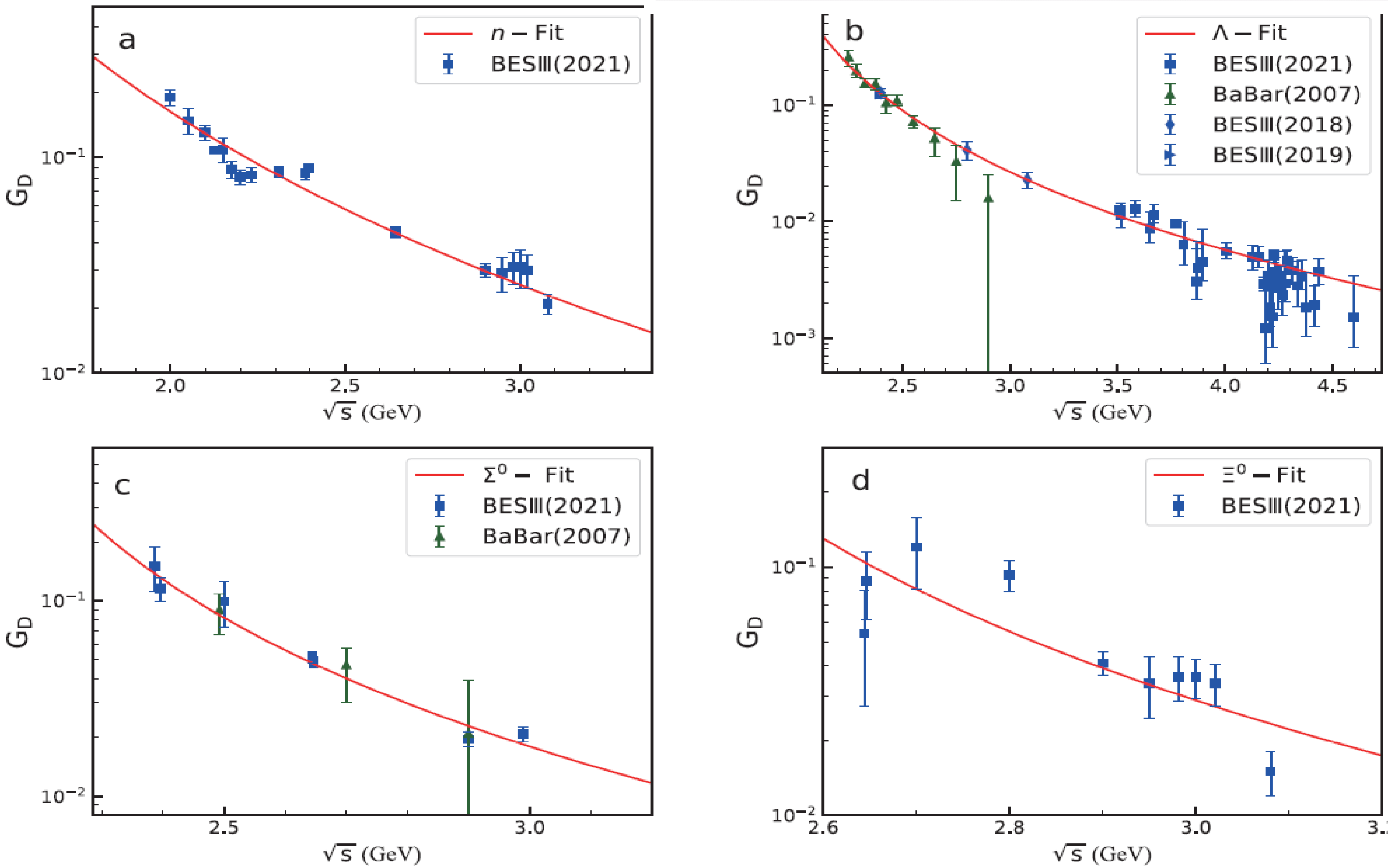
$$G_{\text{eff}} = C_0 g(q^2) = \frac{C_0}{(1-\gamma q^2)^2}$$



National Science Review 8, nwab187 (2021)

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

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

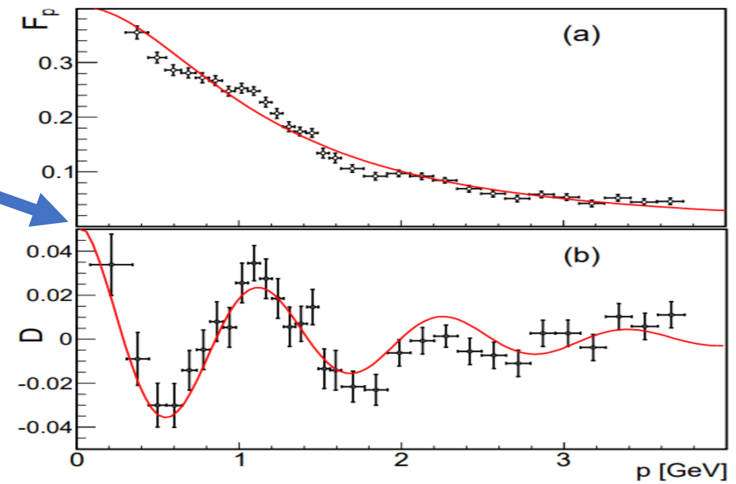


A.X. Dai, Z.Y. Li, L. Chang and J.J. Xie, Chin. Phys. C 46, 073104 (2022).

"Oscillation" of baryon effective form factors

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

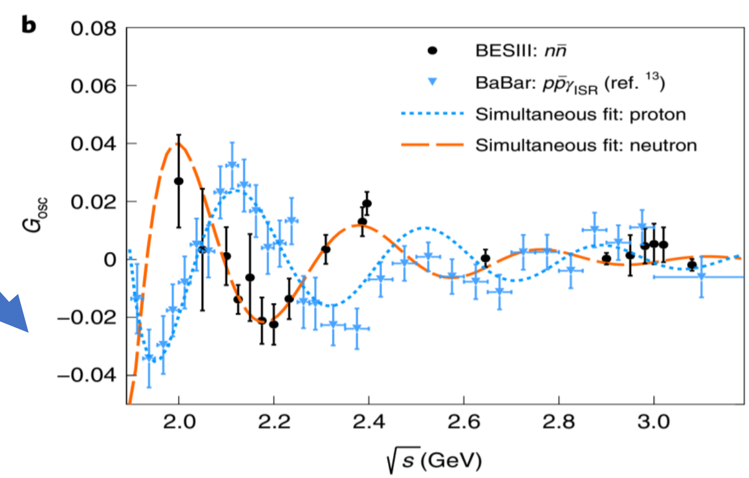
$$G_{eff} = F_{3p} + F_{osc} \quad \rightarrow \quad F_{osc} = data - G_D$$



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

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

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



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

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

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

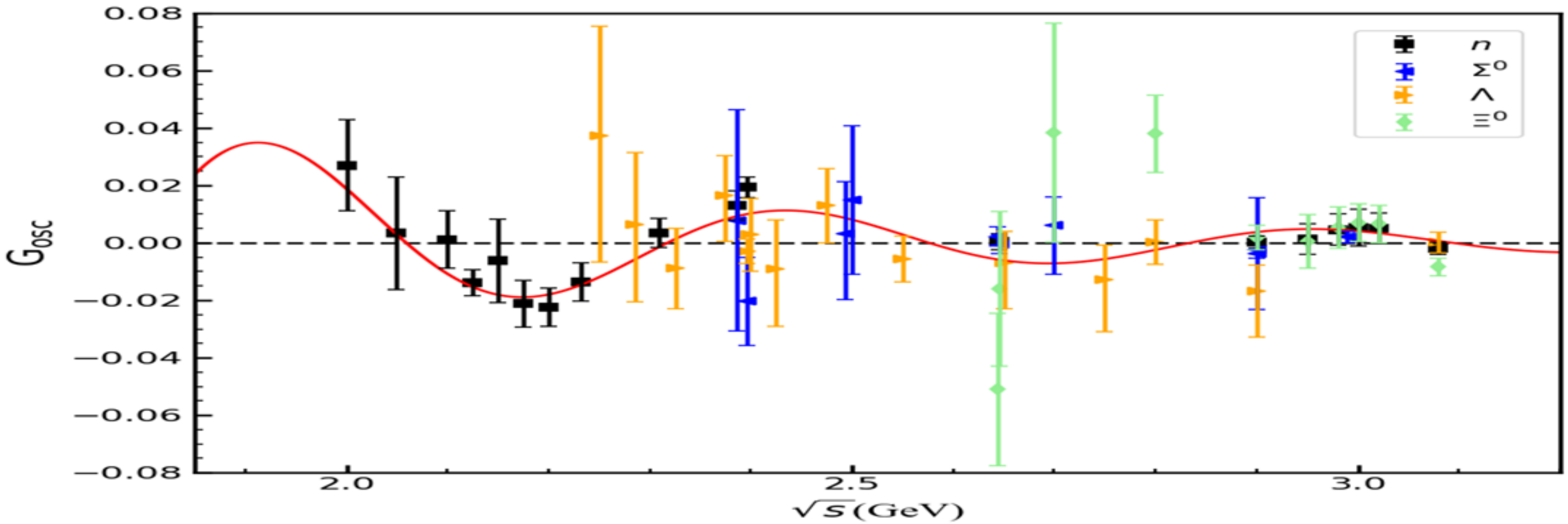
New parametrization for the "oscillation"

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

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

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

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



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

New experimental results

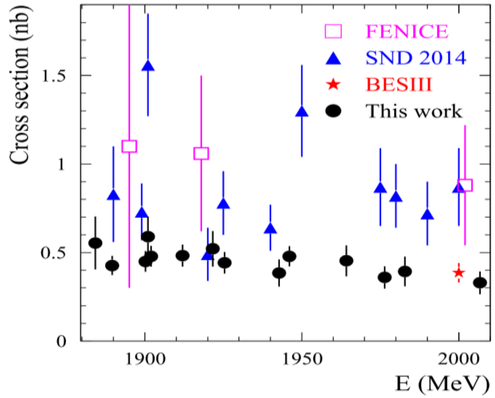
Eur. Phys. J. C (2022) 82:761
https://doi.org/10.1140/epjc/s10052-022-10696-0

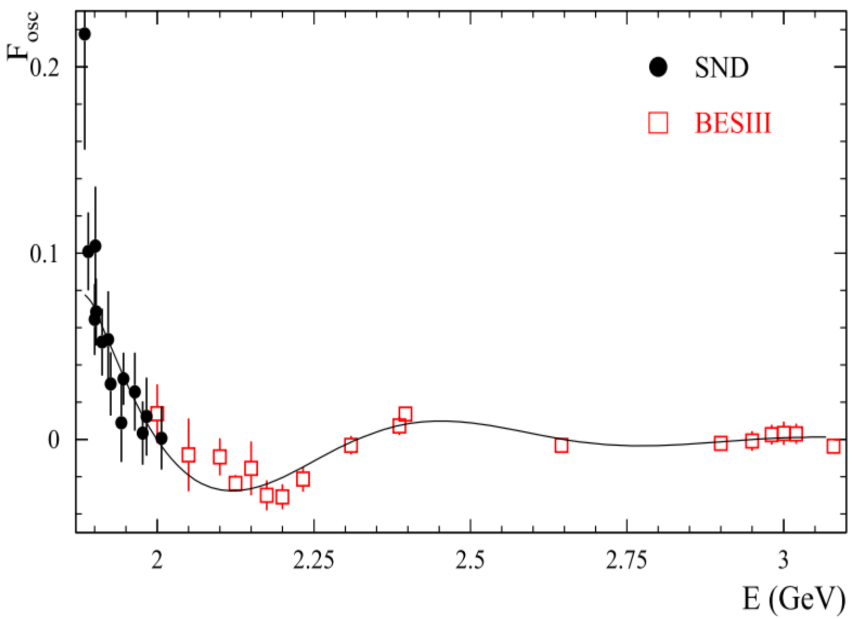
THE EUROPEAN PHYSICAL JOURNAL C

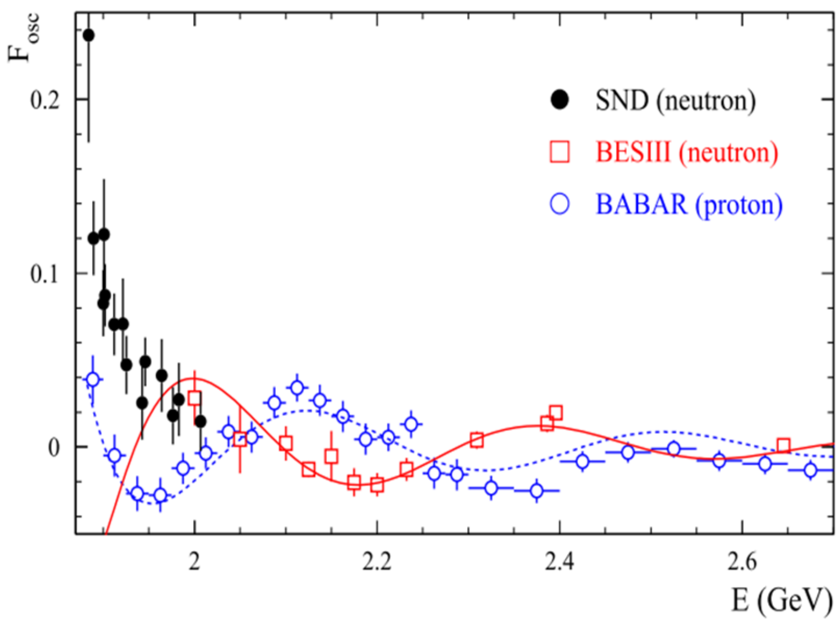
Regular Article - Experimental Physics

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

SND Collaboration



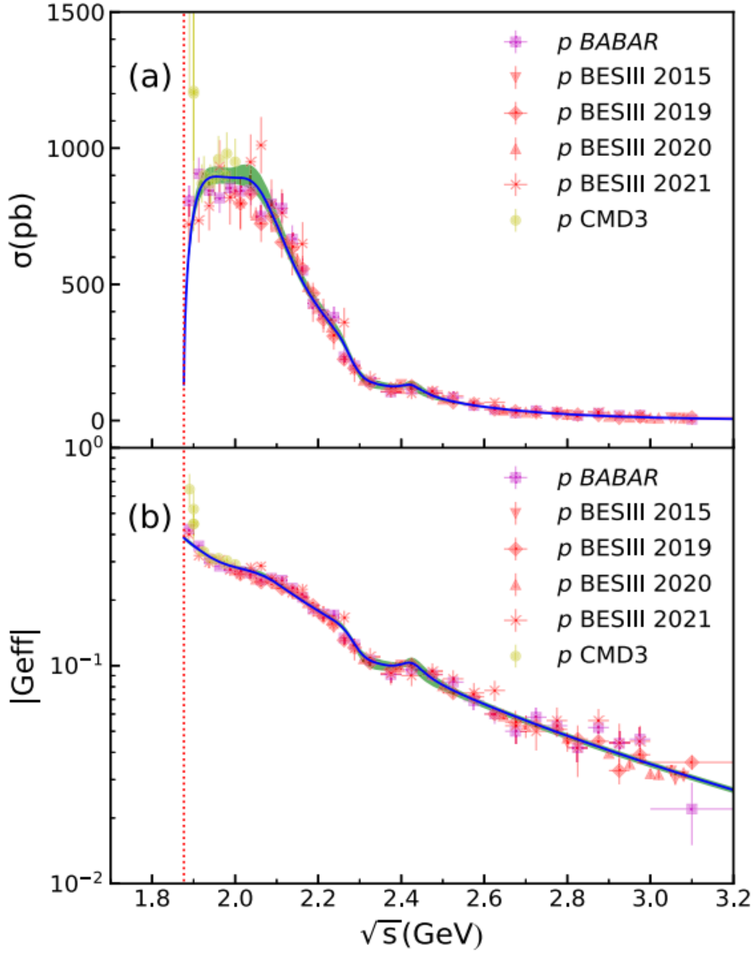




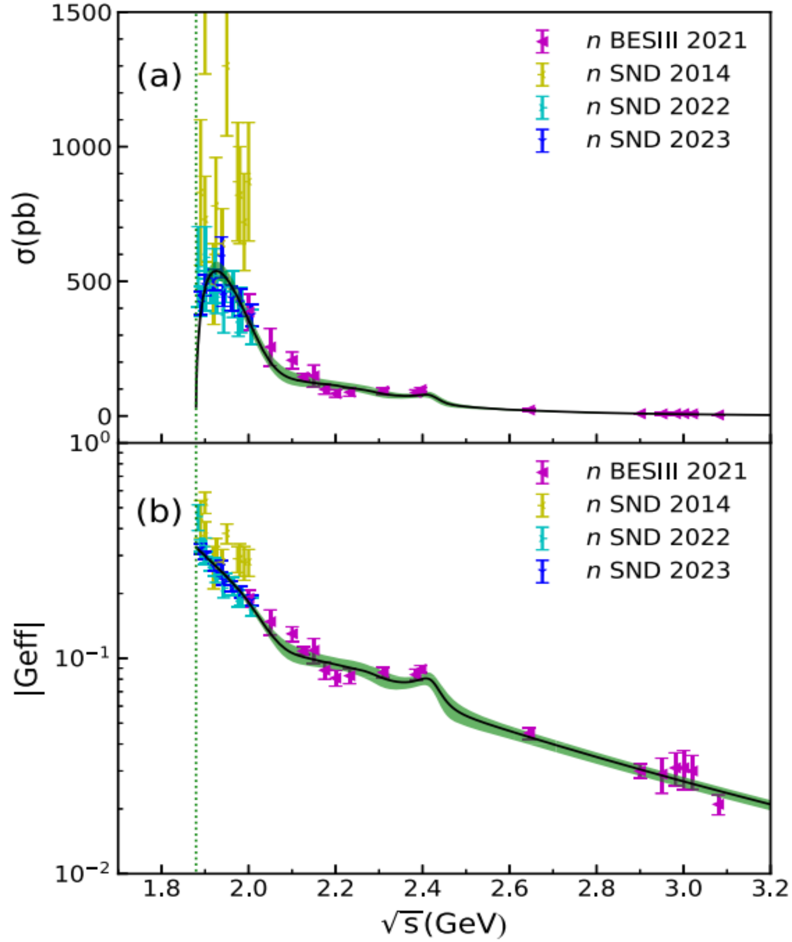
EMFFs of proton and neutron (VMD)

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

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



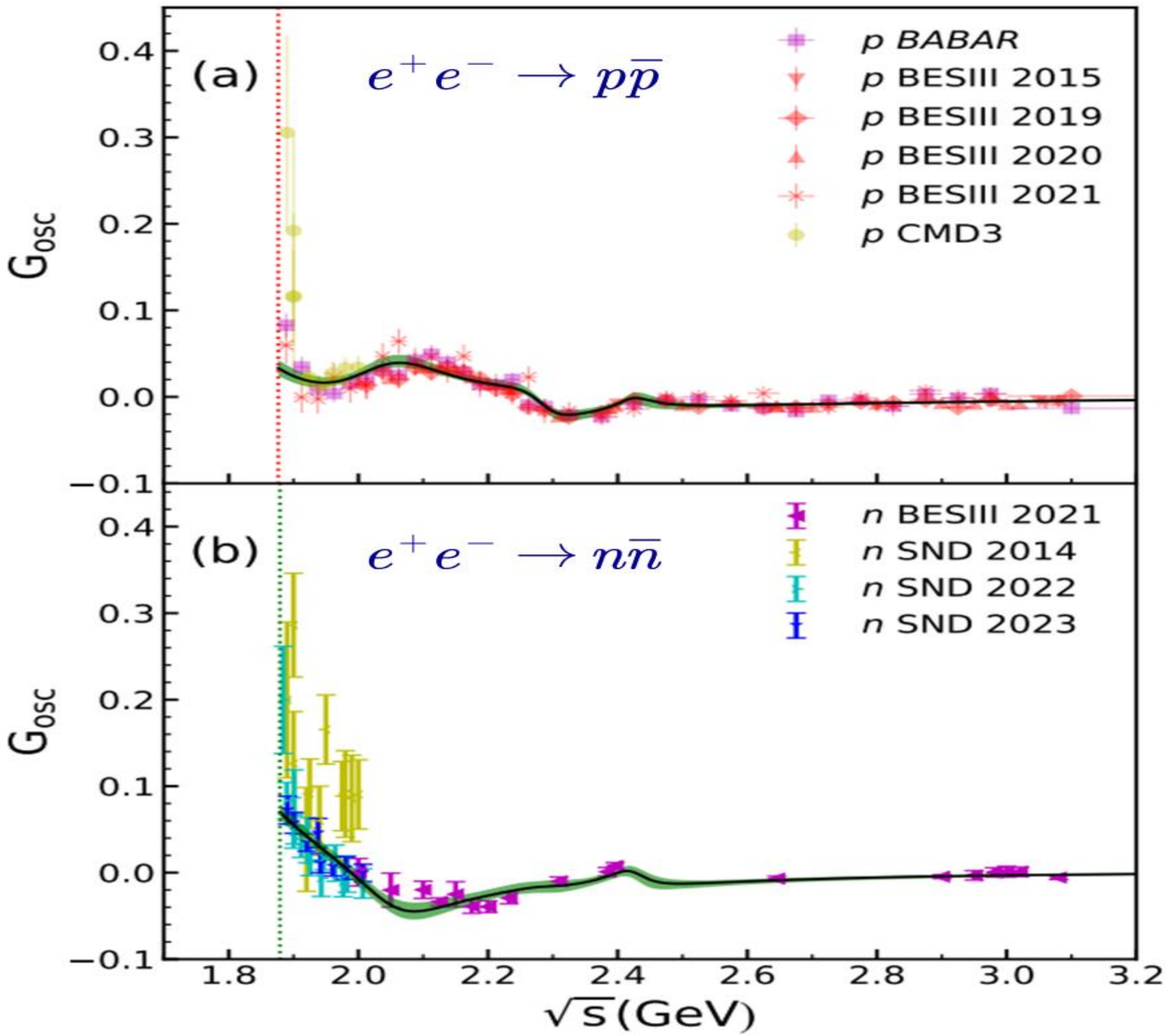
$e^+e^- \to n\bar{n}$



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

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

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

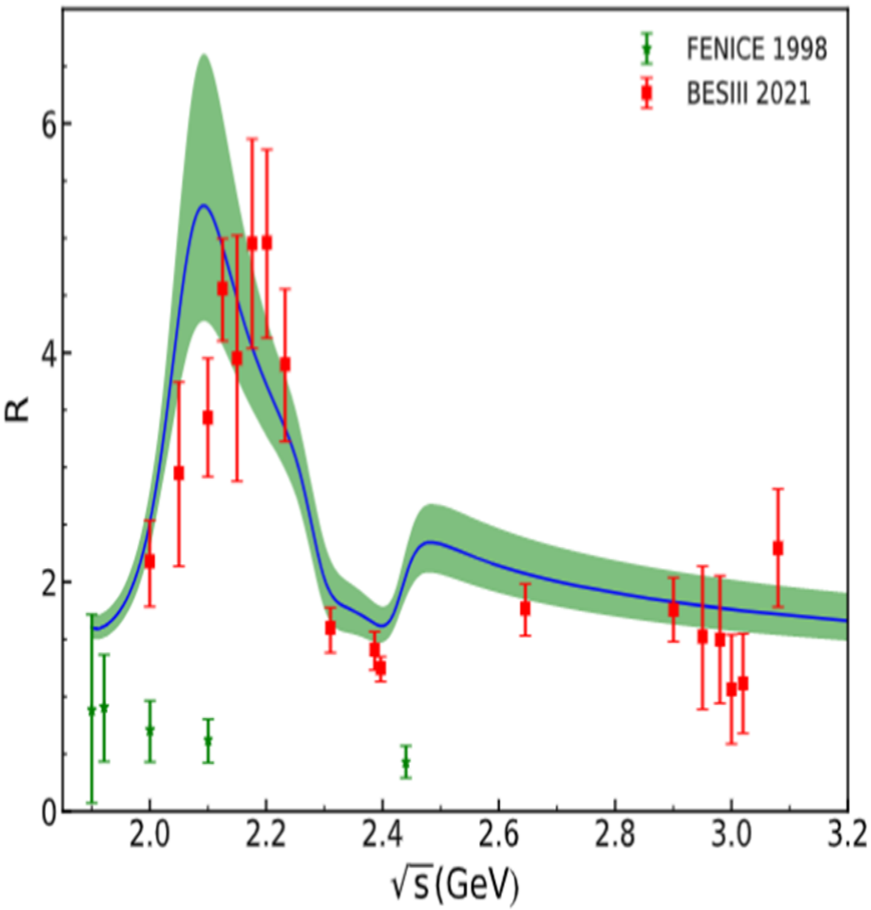


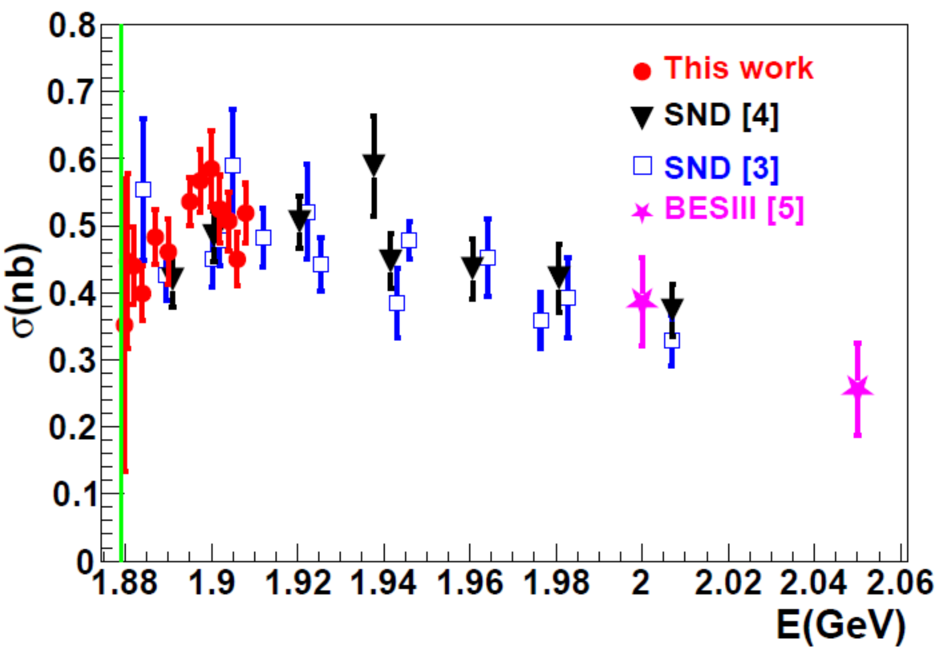
$c_0 = 5.54 \pm 0.02$ for proton

$c_0 = 4.08 \pm 0.04$ for neutron

Cross section of the process $e^+e^- \to n\bar{n}$ near the threshold

$$R = \sigma_{e^+e^- \to p\bar{p}} / \sigma_{e^+e^- \to n\bar{n}}$$

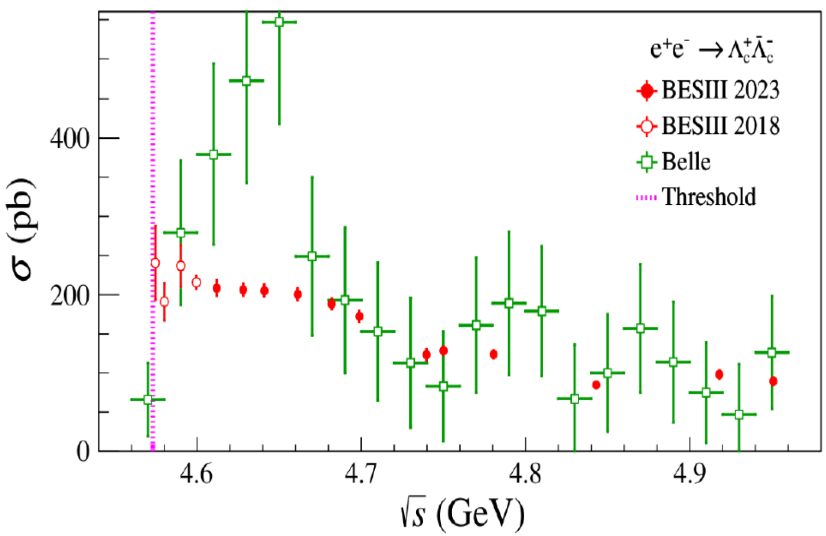


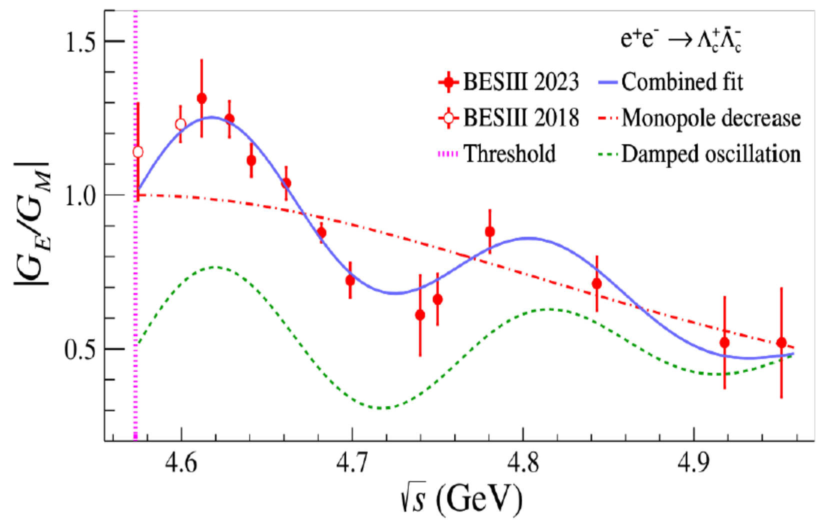


arXiv:2407.15308v1 [hep-ex]

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

PRL.131.191901(2023)



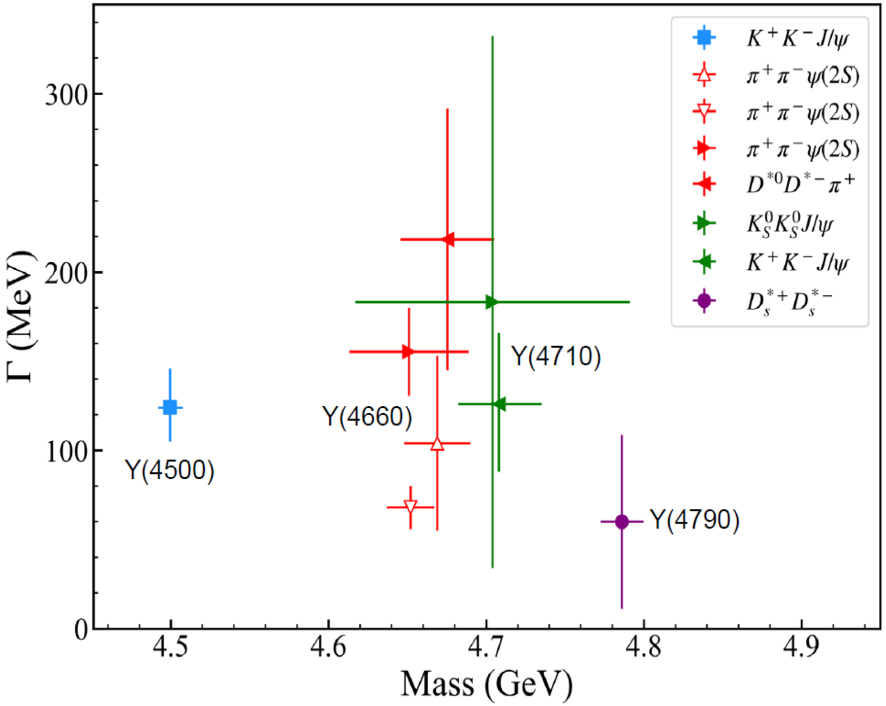


The results of BESIII revealed that there is no peak around $\sqrt{s} = 4.63$ GeV but a long flat from the threshold to 4.68 GeV, diverging from the Belle measurements

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

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

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

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

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

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

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

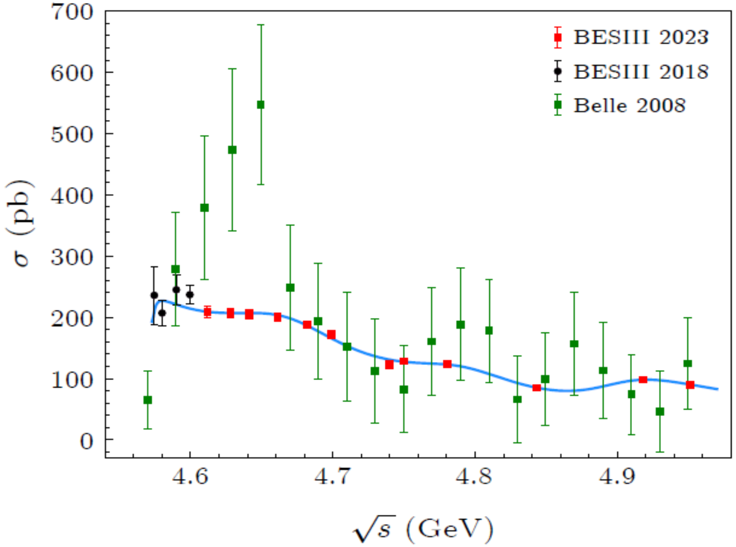
$$g(s) = \frac{1}{(1-\gamma s)^2}$$

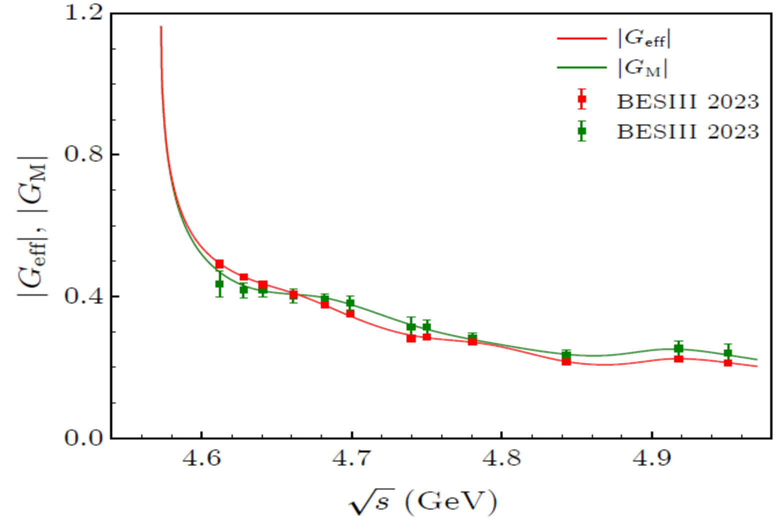
$$\gamma = 0.147 \pm 0.017\ \mathrm{GeV}^{-2}$$

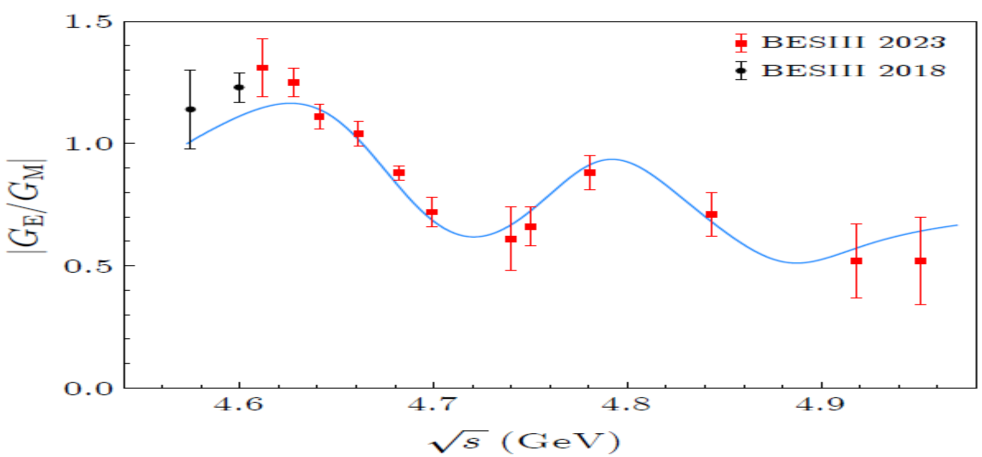
Chinese Physics Letters **41**, 021302 (2024) **Express Letter**

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

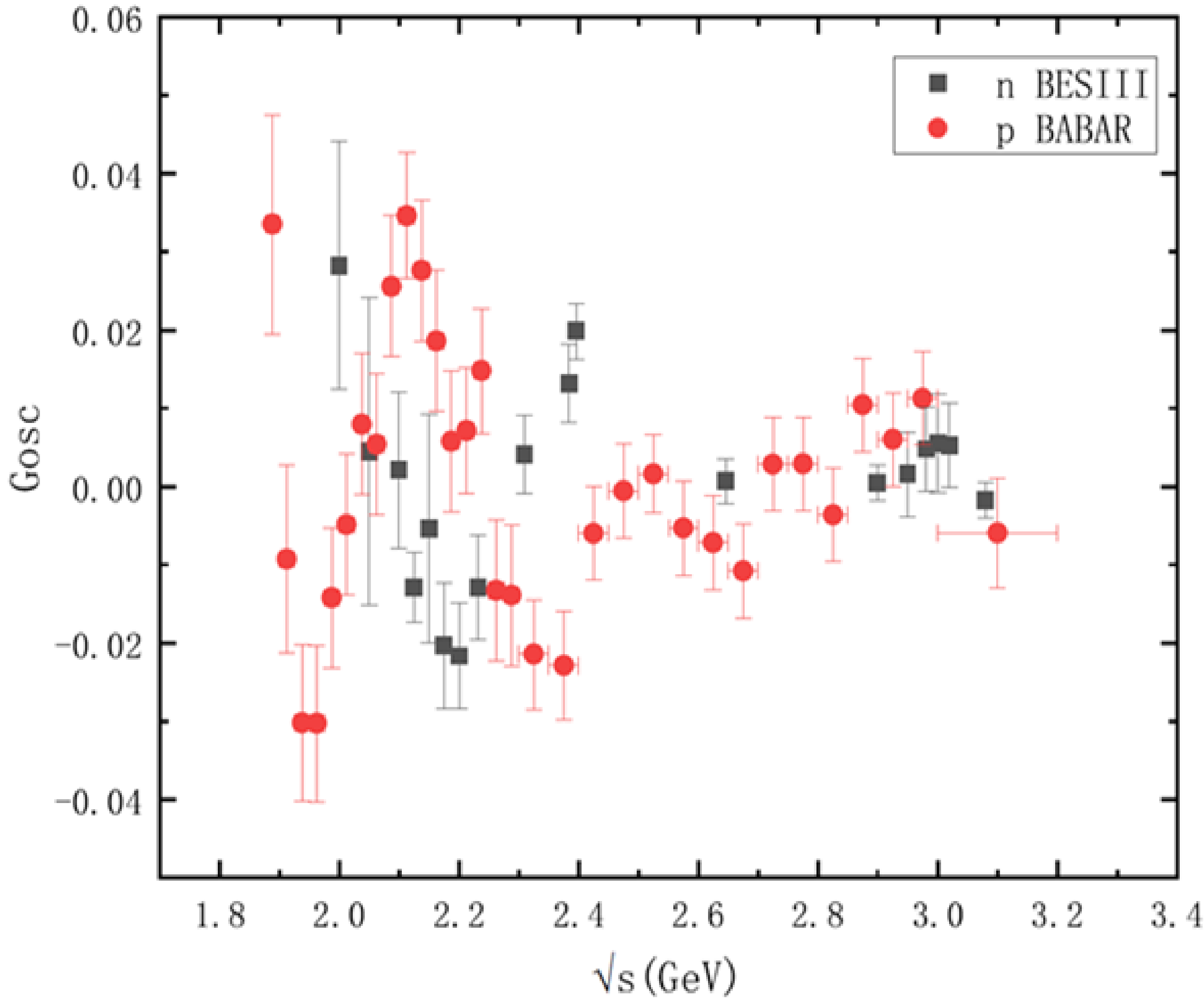
a) Final state interaction   b) Flatté (strong coupling)

2、 "Oscillation" of baryon effective form factors

a) Phenomenology   b) **Vector excited states**

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 vector meson dominance 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!



n BESIII
p BABAR
Gosc
√s (GeV)
0.06
0.04
0.02
0.00
-0.02
-0.04
1.8
2.0
2.2
2.4
2.6
2.8
3.0
3.2
3.4