

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

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2025年9月19日@第七届粒子物理天问论坛
湖北 武汉 中国地质大学

Outline

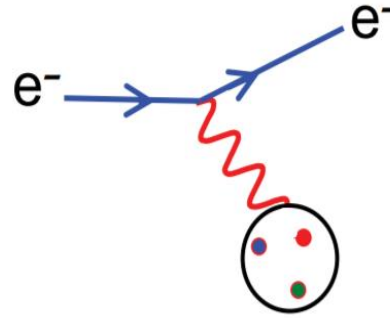
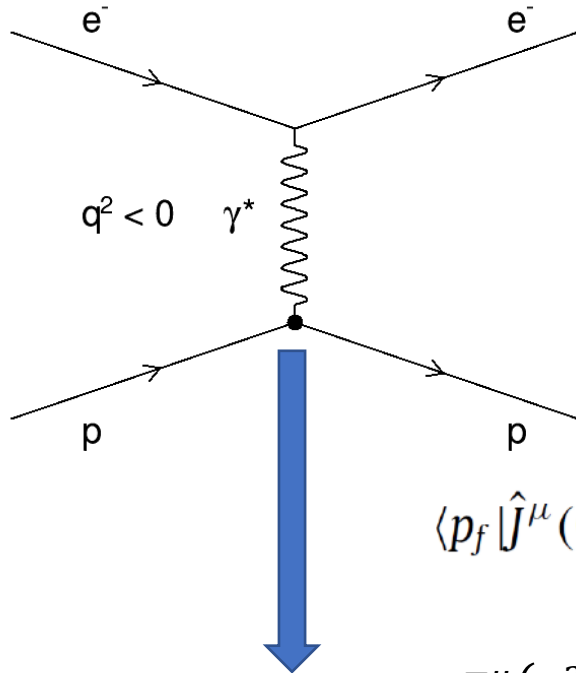
Introduction: Electromagnetic Form Factors

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

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

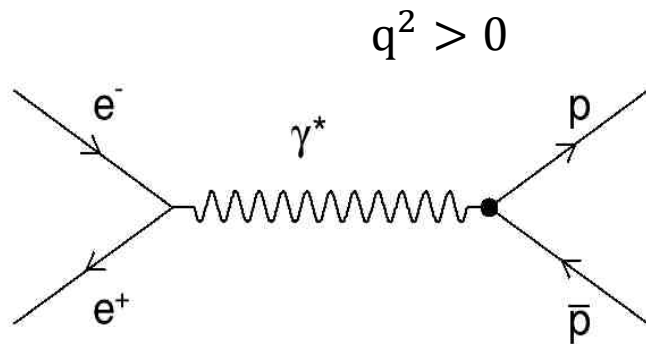
$$\Gamma^\mu(q^2) = \gamma^\mu F_1^p(q^2) + i \frac{F_2^p(q^2)}{2M_p} \sigma^{\mu\nu} q_\nu$$

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

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

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)

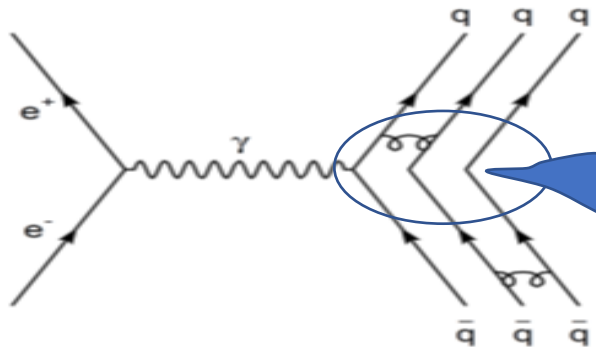


$$\left(\frac{d\sigma}{d\Omega} \right)_{e^+e^- \rightarrow N\bar{N}}^{th} = \frac{\alpha^2 \beta}{4q^2} C_N(q^2) \left\{ |G_M^N(q^2)|^2 (1 + \cos^2 \theta) + |G_E^N(q^2)|^2 \frac{1}{\tau} \sin^2 \theta \right\}$$

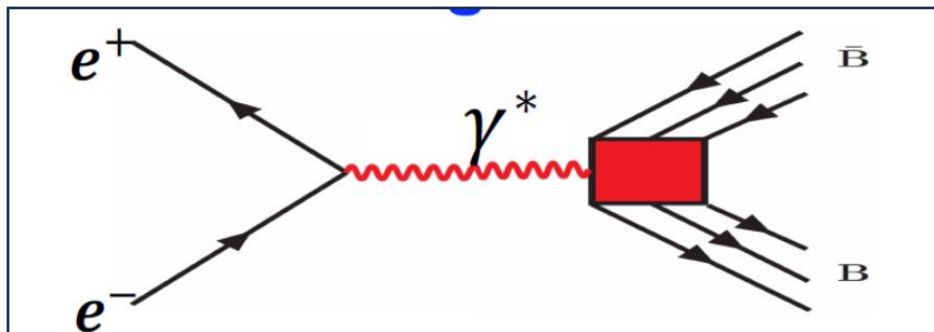
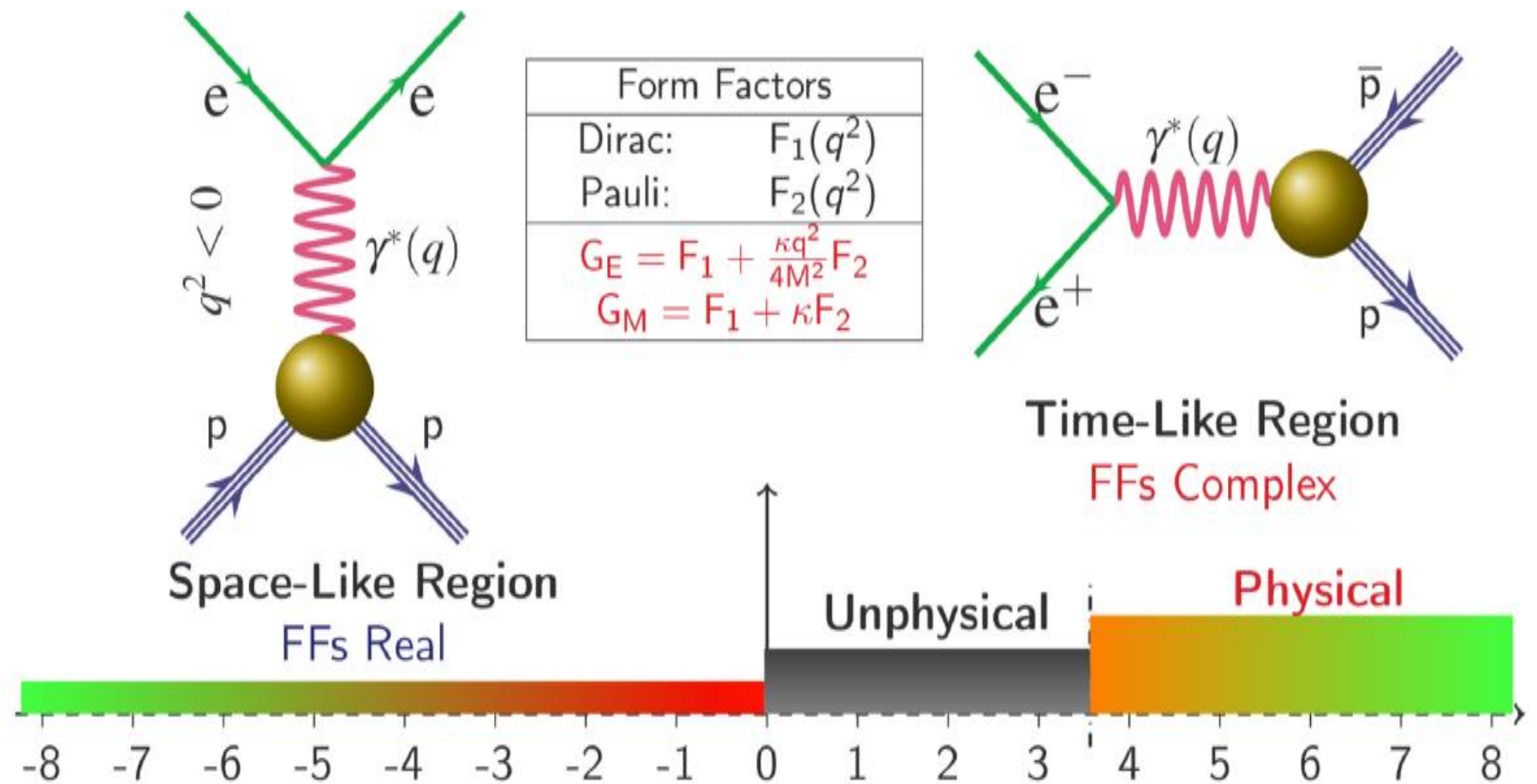
$$\sigma_{e^+e^- \rightarrow N\bar{N}}^{th} = \frac{\alpha^2 \beta}{4q^2} C_N(q^2) \int d\Omega \left[|G_M^N(q^2)|^2 (1 + \cos^2 \theta) + |G_E^N(q^2)|^2 \frac{\sin^2 \theta}{\tau} \right]$$

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

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



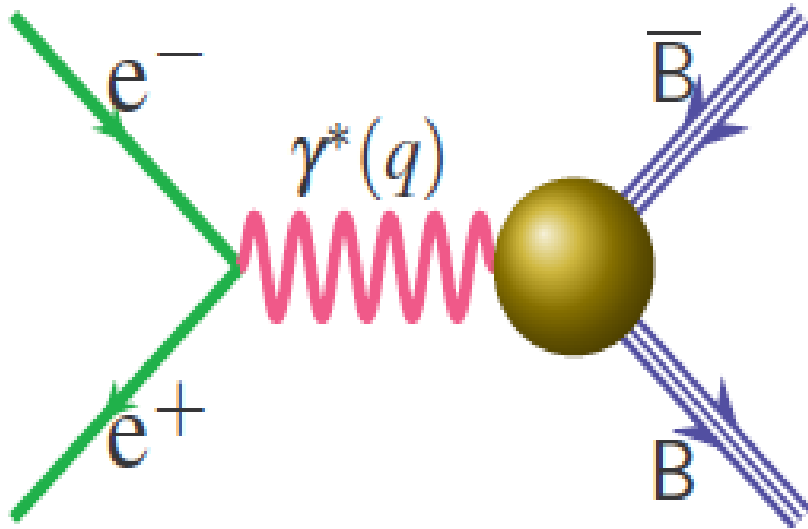
$$|G_{eff}(q^2)| = \sqrt{\frac{\sigma(q^2)}{\sigma_{point}(q^2)}} = \sqrt{\frac{|G_M(s)|^2 + \frac{2M_s^2}{s} |G_E(s)|^2}{1 + \frac{2M_s^2}{s}}}$$



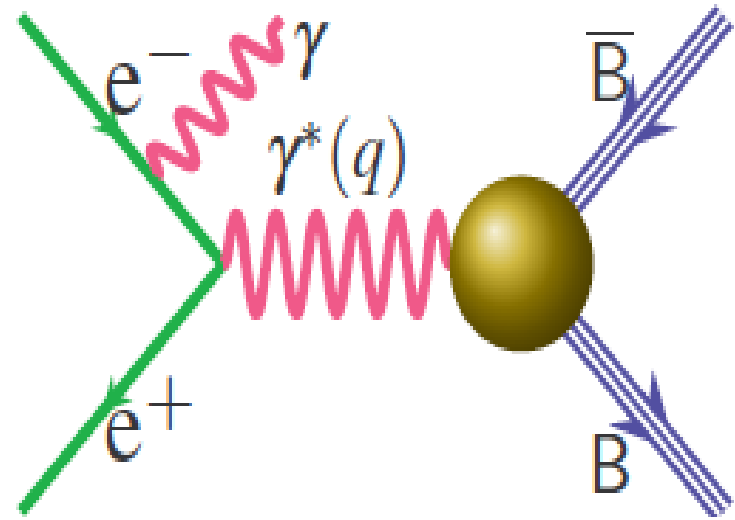
From QED to QCD

Both QED and QCD

Experimental measurements (time-like)



Energy Scan



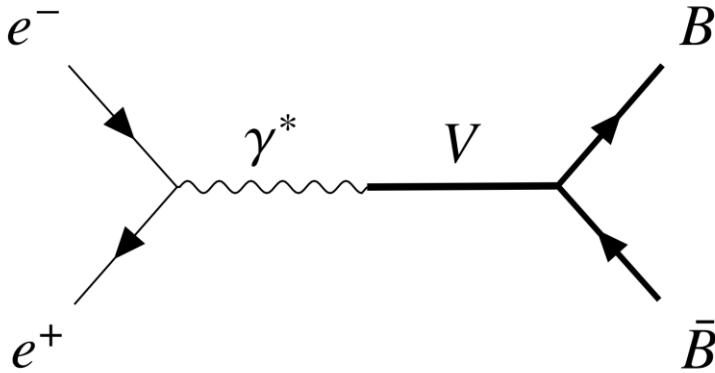
Initial State Radiation

Both techniques can be used
on the experimental side.

VMD: vector meson dominance model

$$\mathcal{L}_{V\gamma} = \sum_V \frac{eM_V^2}{f_V} V_\mu A^\mu$$

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

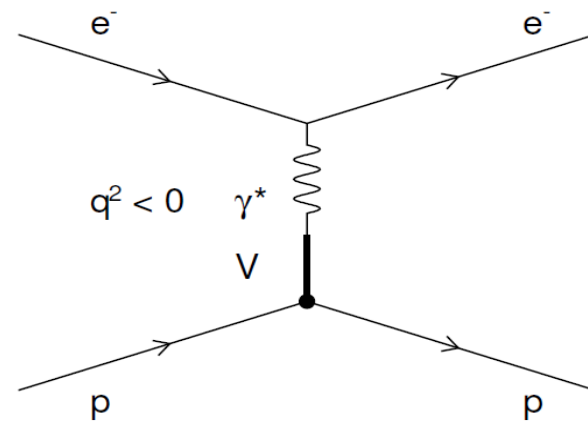
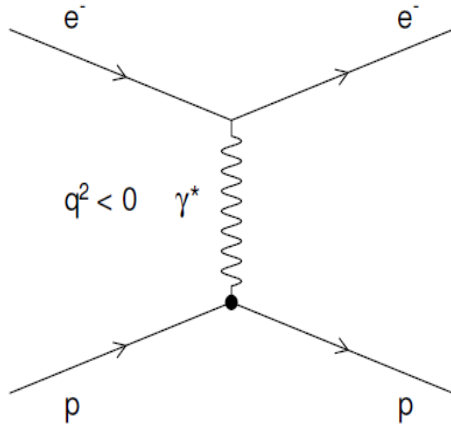


$$\Gamma_\mu^V = g_V \gamma_\mu + i \frac{\kappa_V}{2M} \sigma_{\mu\nu} q^\nu$$

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

$$\Rightarrow \left\{ \begin{array}{l} F_1(q^2) = \sum_V \beta_V \frac{M_V^2}{M_V^2 - q^2}, \quad \beta_V = \frac{g_V}{f_V} \\ F_2(q^2) = \sum_V \alpha_V \frac{M_V^2}{M_V^2 - q^2}, \quad \alpha_V = \frac{\kappa_V}{f_V} \end{array} \right.$$

VMD for nucleon



Dirac and Pauli isoscalar and isovector form factors are

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

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

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

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



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

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

$$G_E = F_1 - \tau F_2$$

$$G_M = F_1 + F_2$$

SEMI-PHENOMENOLOGICAL FITS TO NUCLEON ELECTROMAGNETIC FORM FACTORS

F. IACHELLO* and A.D. JACKSON**

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

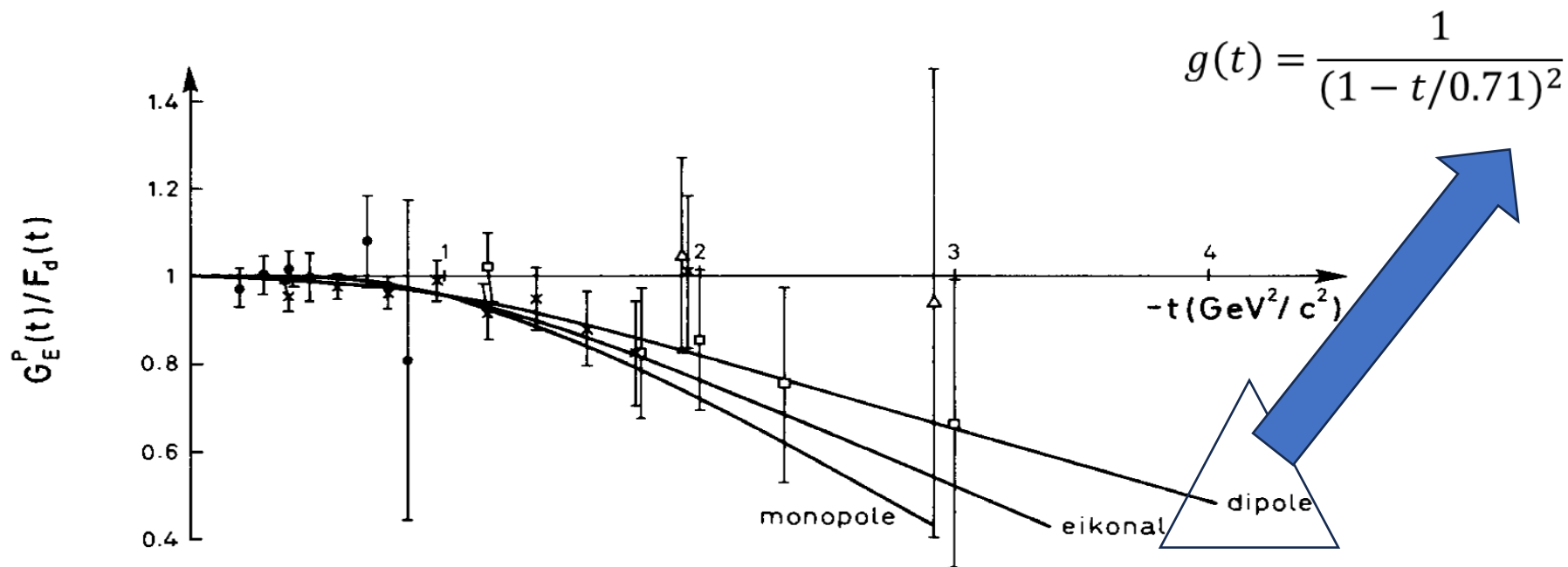
and

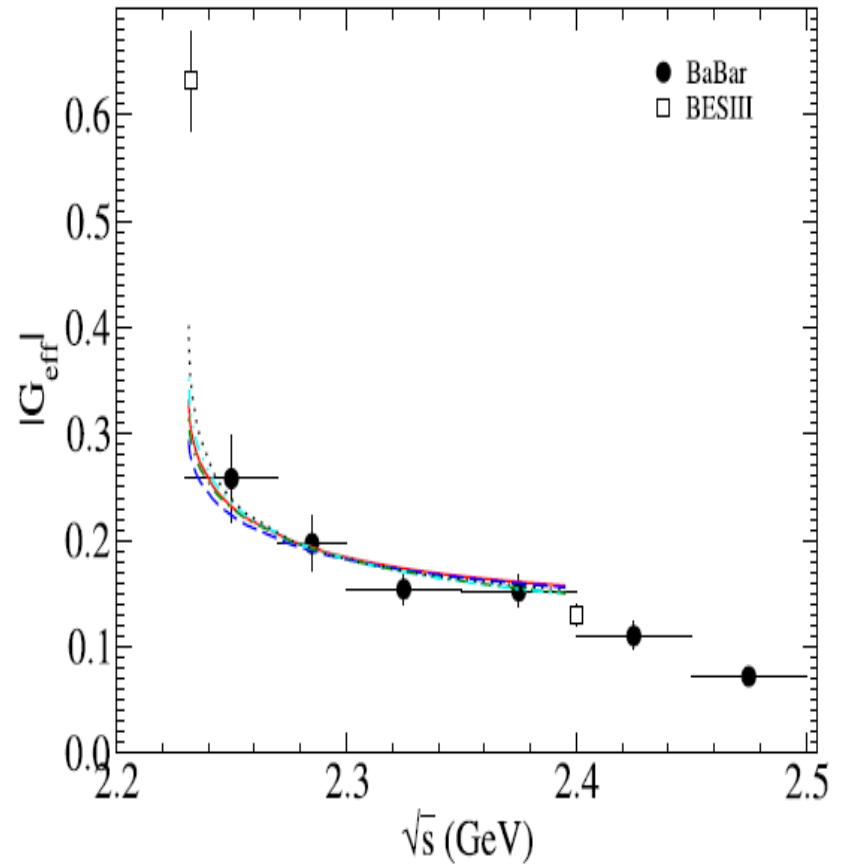
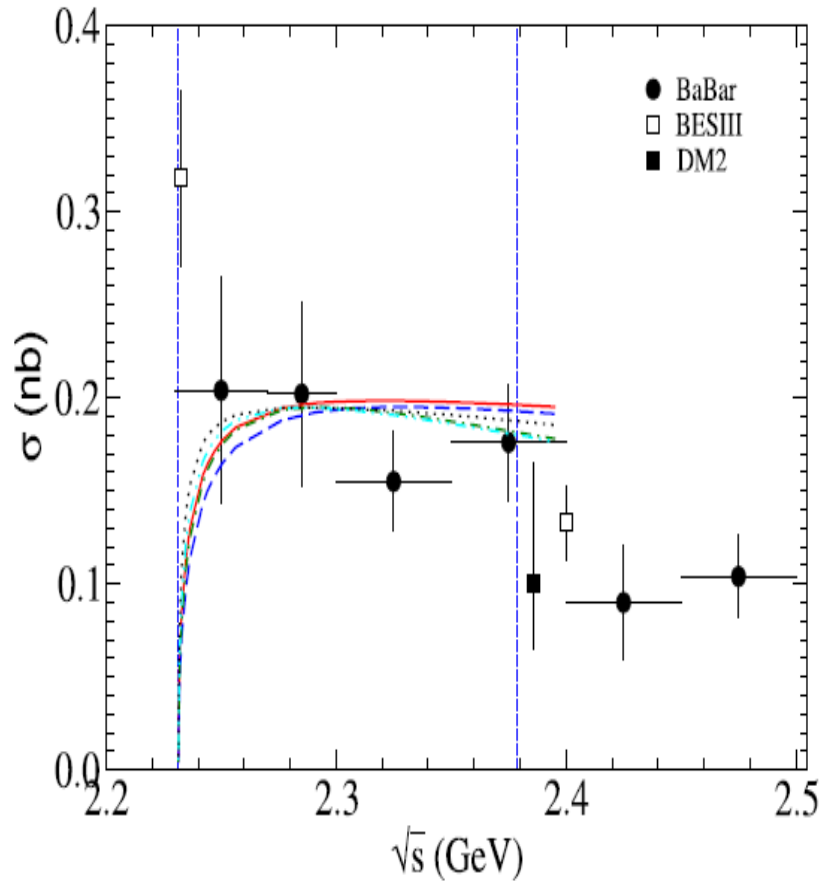
A. LANDE

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

Received 31 August 1972

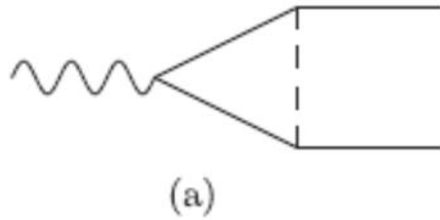
Several theoretically interesting forms of the nucleon EM form factor have been considered and found to provide quantitative descriptions of available data with as few as three adjustable parameters.



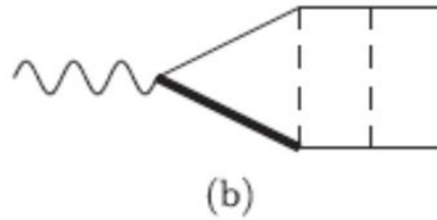


J. Haidenbauer and U. G. Meißner, Phys. Lett. B 761, 456-461(2016).

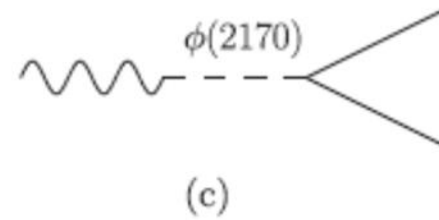
Threshold enhancement: final state interaction



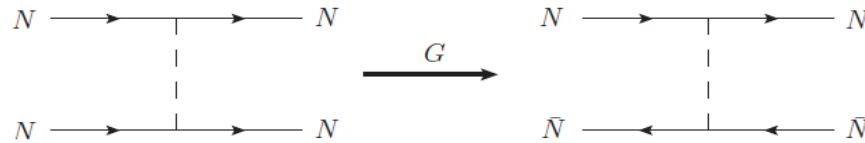
FSI-meson exchange



N-excitation (Δ)*



First flavorless vector meson



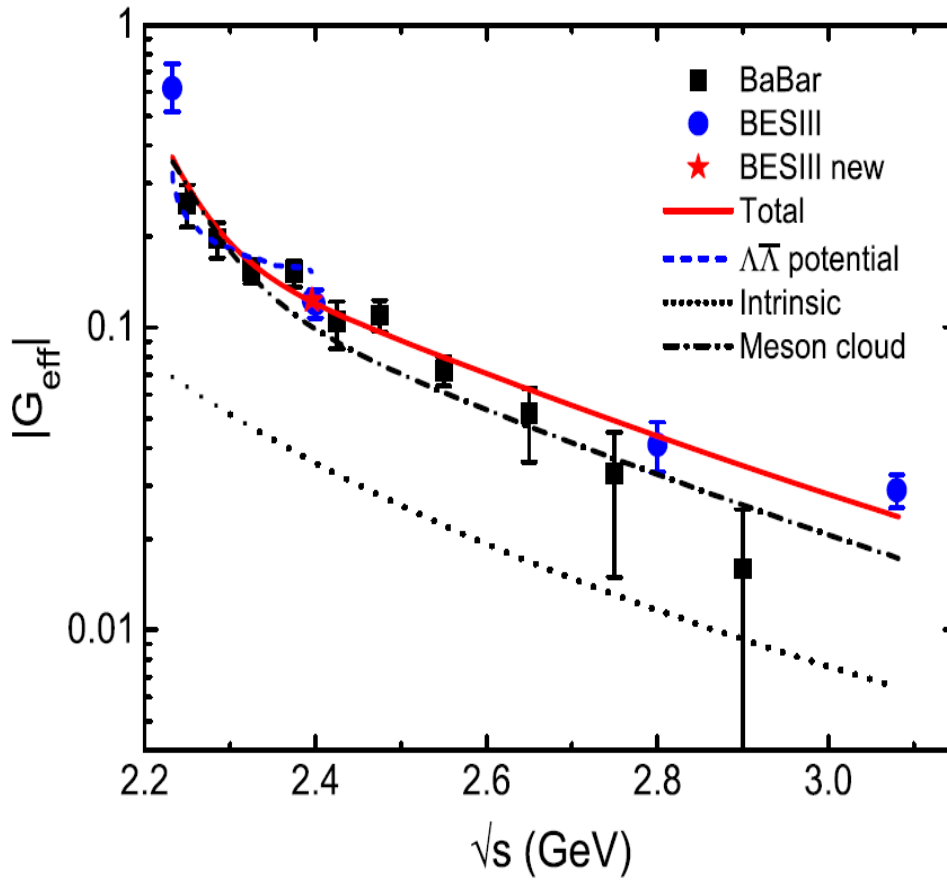
$$V_{\bar{N}N}^{\text{OBE}} = (-1)^I V_{NN}^{\text{OBE}}, \quad V_{\bar{N}N}^{\text{TBE}} = (-1)^{I_1+I_2} V_{NN}^{\text{TBE}}$$

$$T_{L''L'}(p'', p'; E_k) = V_{L''L'}(p'', p')$$

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

I.T. Lorenz, H.W. Hammer and U.G. Meissner, **Phys. Rev. D****92**, 034018 (2015).

Q.H. Yang, L.Y. Dai, D. Guo, J. Haidenbauer, X.W. Kang and U.G. Meissner, **Sci. Bull.** **68**, 2729-2733 (2023), arXiv:2206.01494.

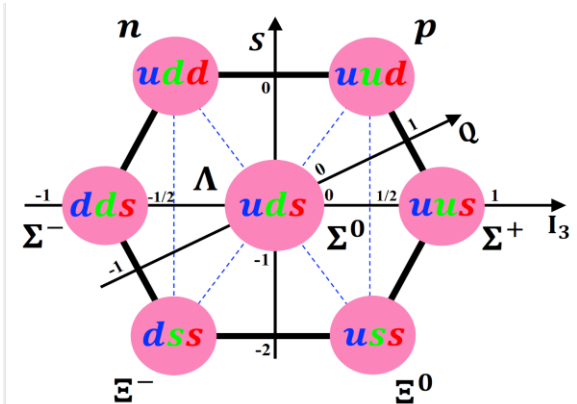


State	Mass	Width	State	Mass	Width
$\omega(782)$ [55]	782	8.1	$\phi(1020)$ [56]	1019	4.2
$\omega(1420)$ [57]	1418	104	$\phi(1680)$ [57]	1674	165
$\omega(1650)$ [57]	1679	121	$\phi(2170)$ [58]	2171	128

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 $g(q^2)$

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

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



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

EMFFs of Λ in the VMD (new proposal)

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

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

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

$$Q^2 \rightarrow -q^2$$

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

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

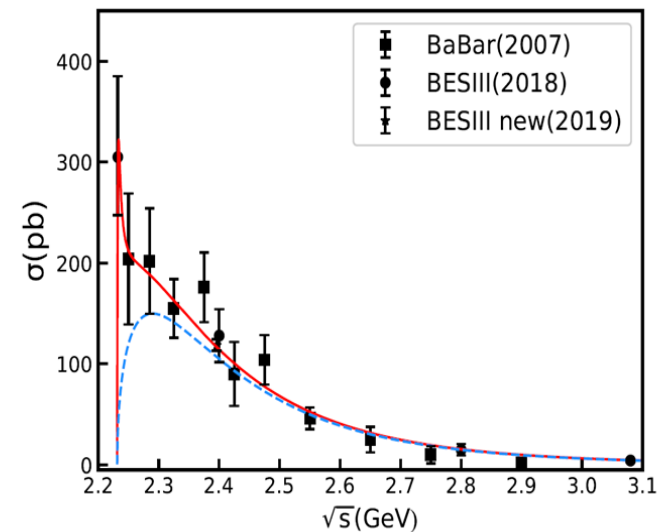
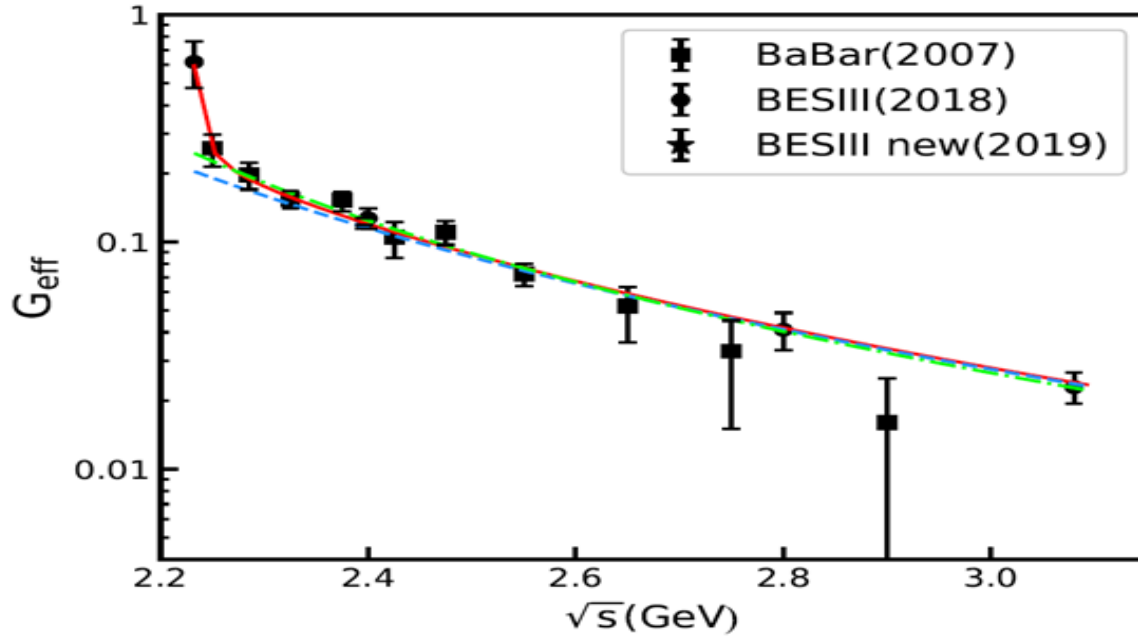


Figure: Cross section of the reaction $e^+e^- \rightarrow \bar{\Lambda}\Lambda$.

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
$\gamma \text{ (GeV}^{-2}\text{)}$	0.43	β_ω	-1.13
β_ϕ	1.35	α_ϕ	-0.40
β_x	0.0015	$m_x \text{ (MeV)}$	2230.9
$\Gamma_x \text{ (MeV)}$	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).

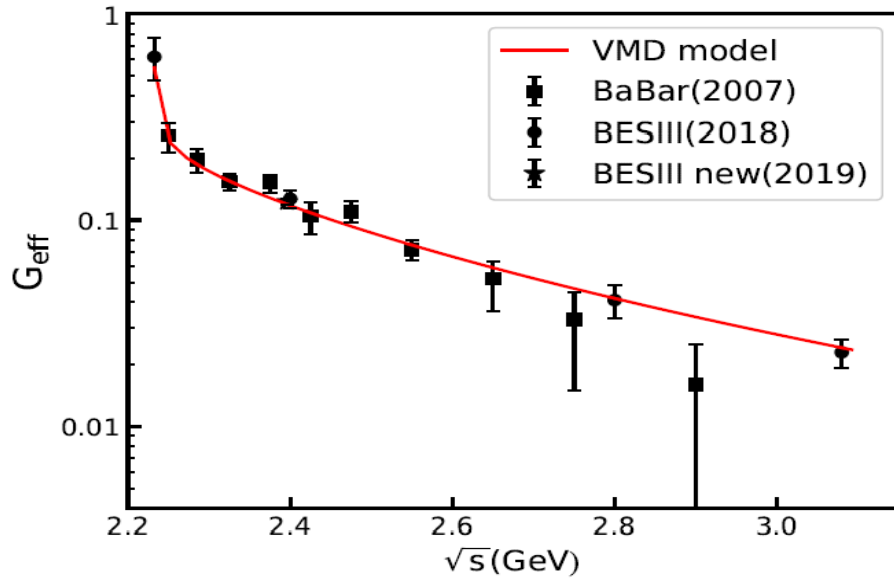


Figure: Fitting result of $|G_{eff}|$ with Flatte.

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

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

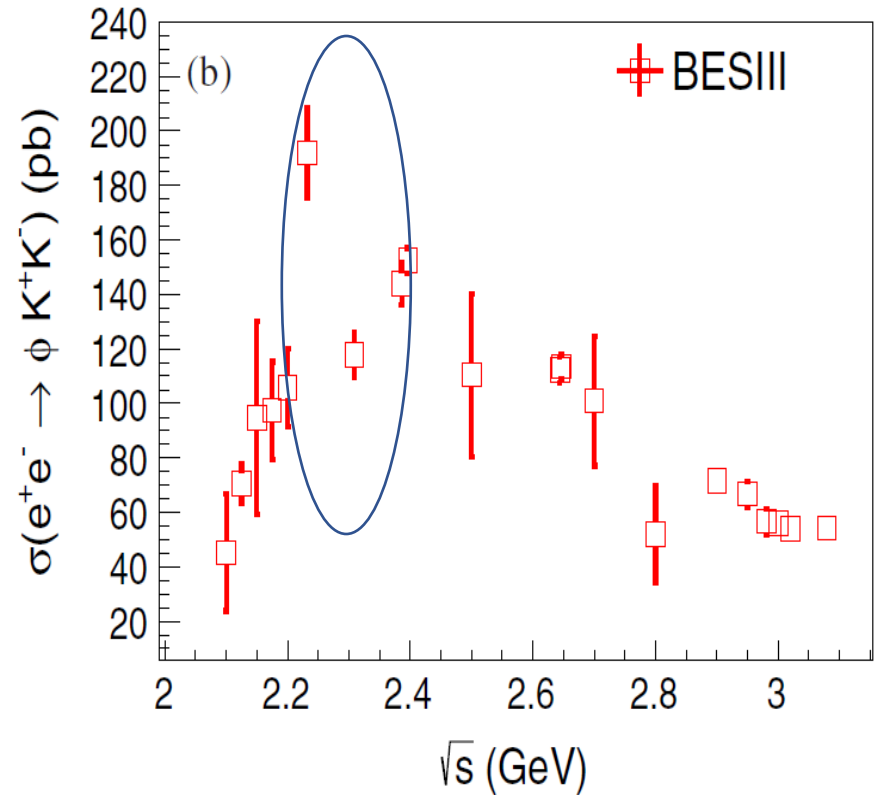
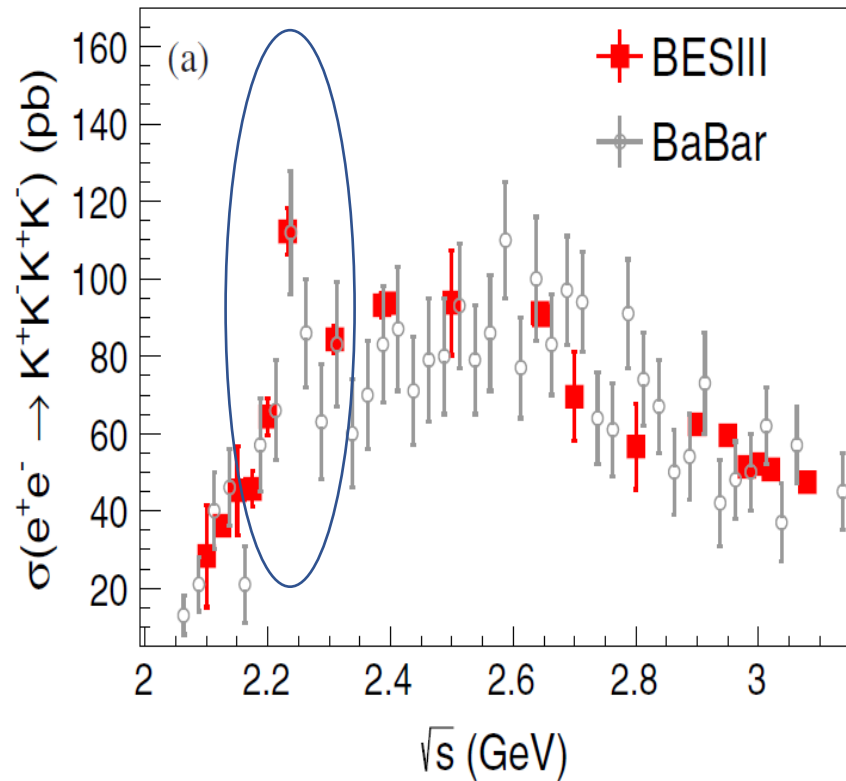
$$\Gamma_{K\bar{K}} = \begin{cases} g_K \sqrt{(1/4)m^2 - m_K^2} & \text{above threshold} \\ i g_K \sqrt{m_K^2 - (1/4)m^2} & \text{below threshold} \end{cases}$$

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

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

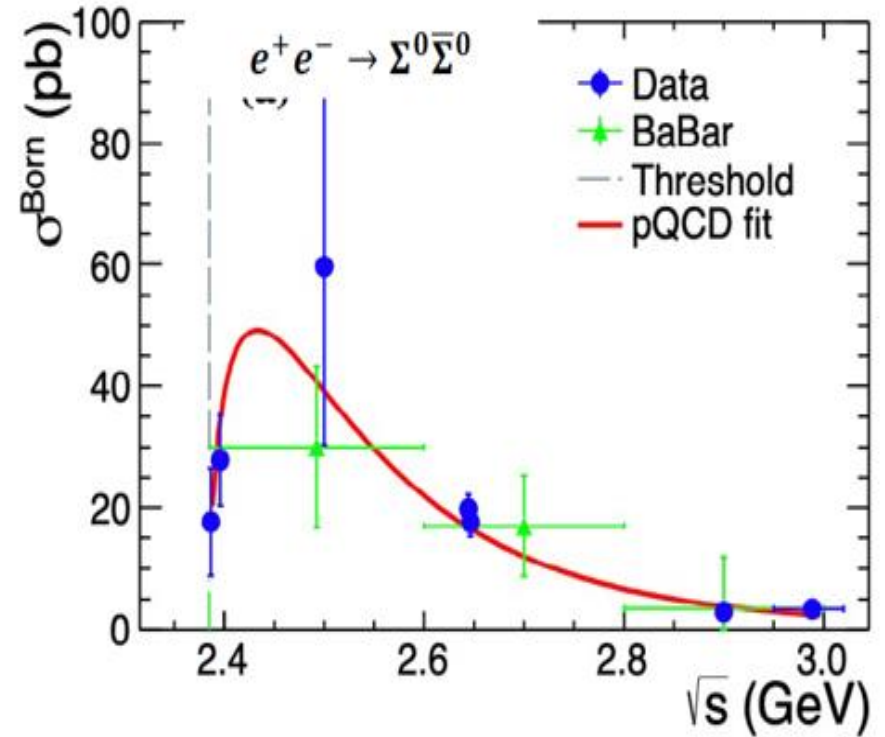
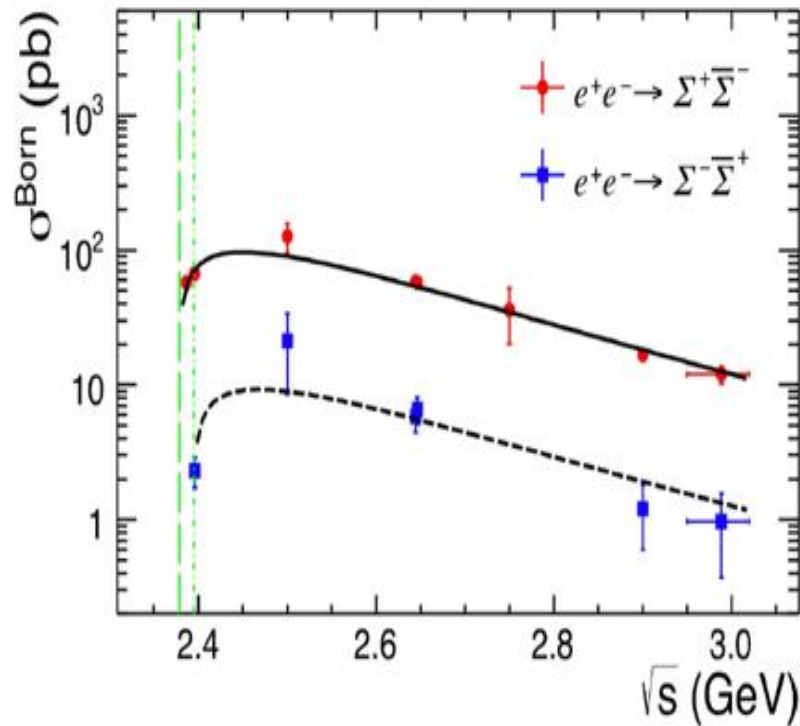
Z. Y. Li, A. X. Dai and J. J. Xie, Chin. Phys. Lett. 39, 011201 (2022).

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)

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

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

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



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

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

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

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

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

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

Isospin
decomposition

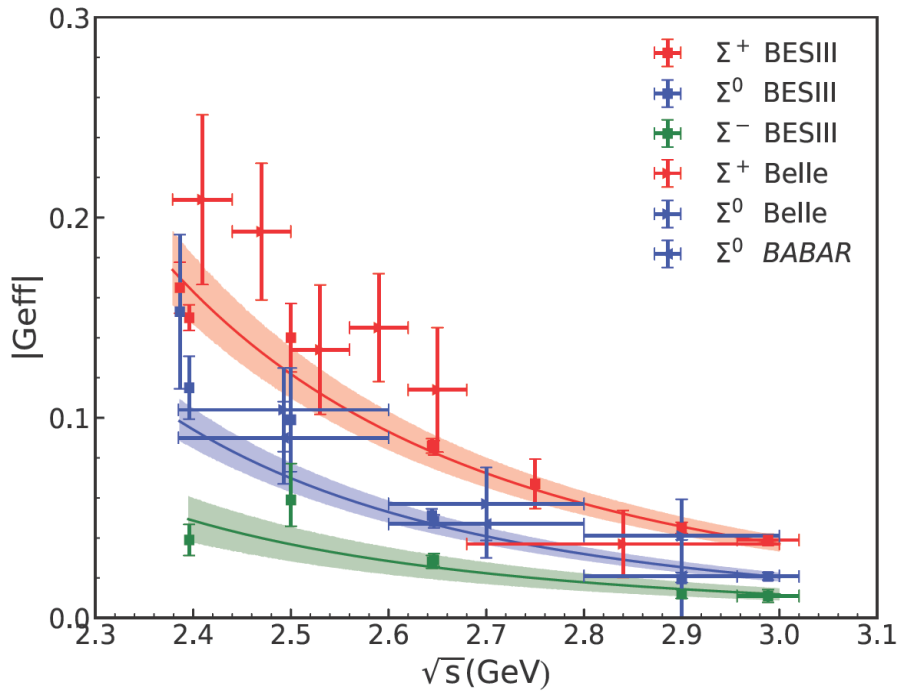
$$B_\rho = \frac{m_\rho^2}{m_\rho^2 - q^2 - im_\rho \Gamma_\rho},$$

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

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

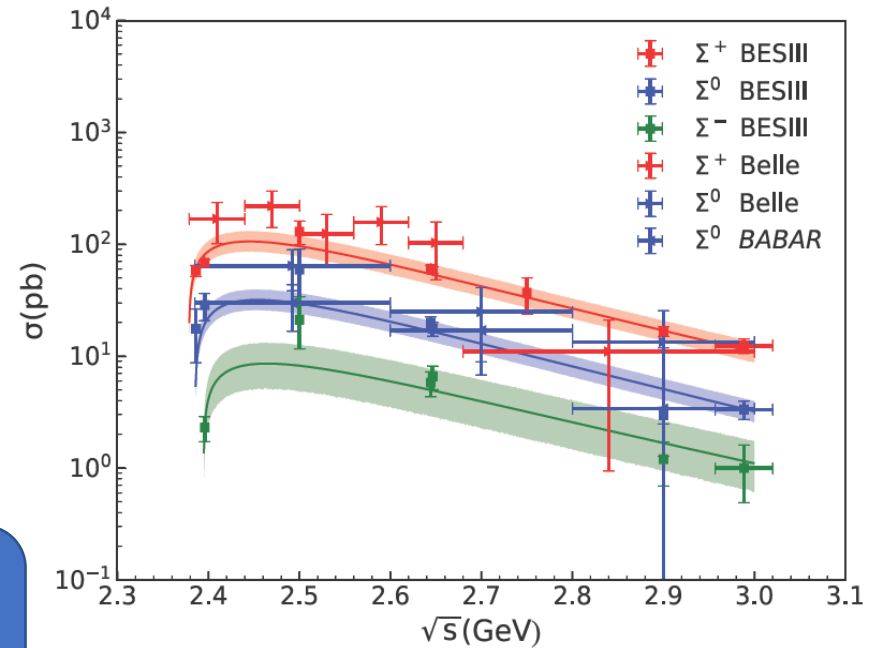
$$f_1^{\Sigma^-} = -1 + \frac{\beta_\rho}{\sqrt{2}} + \frac{\beta_{\omega\phi}}{\sqrt{3}}, \quad f_2^{\Sigma^-} = -0.479 + \frac{\alpha_{\omega\phi}}{\sqrt{3}},$$

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



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

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



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

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

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



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

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

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

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

$$m_{V_1} = 2.742 \pm 0.007 \text{ GeV}$$

$$\Gamma_{V_1} = 71 \pm 28 \text{ MeV}$$

MGI model

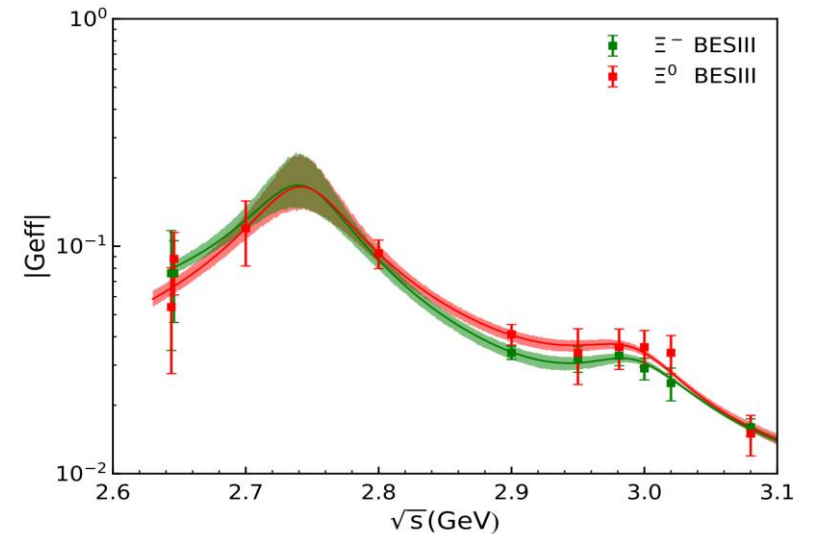
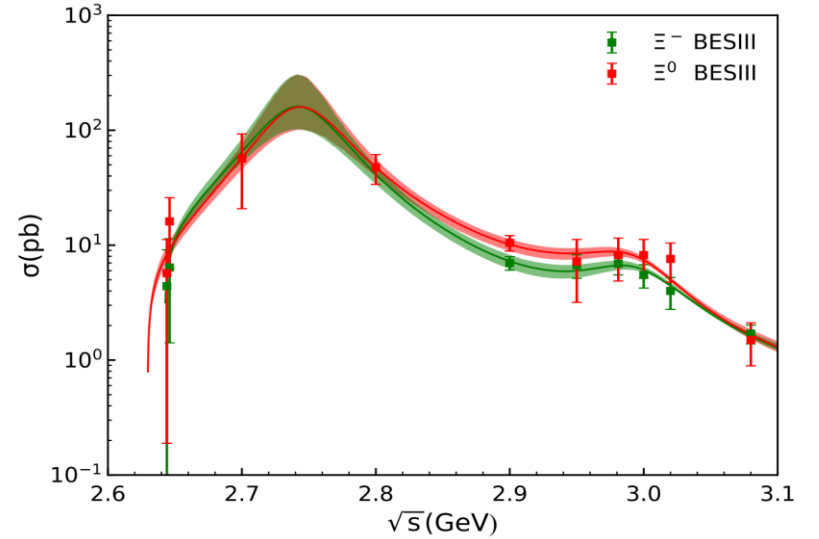
QCD sum rule

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

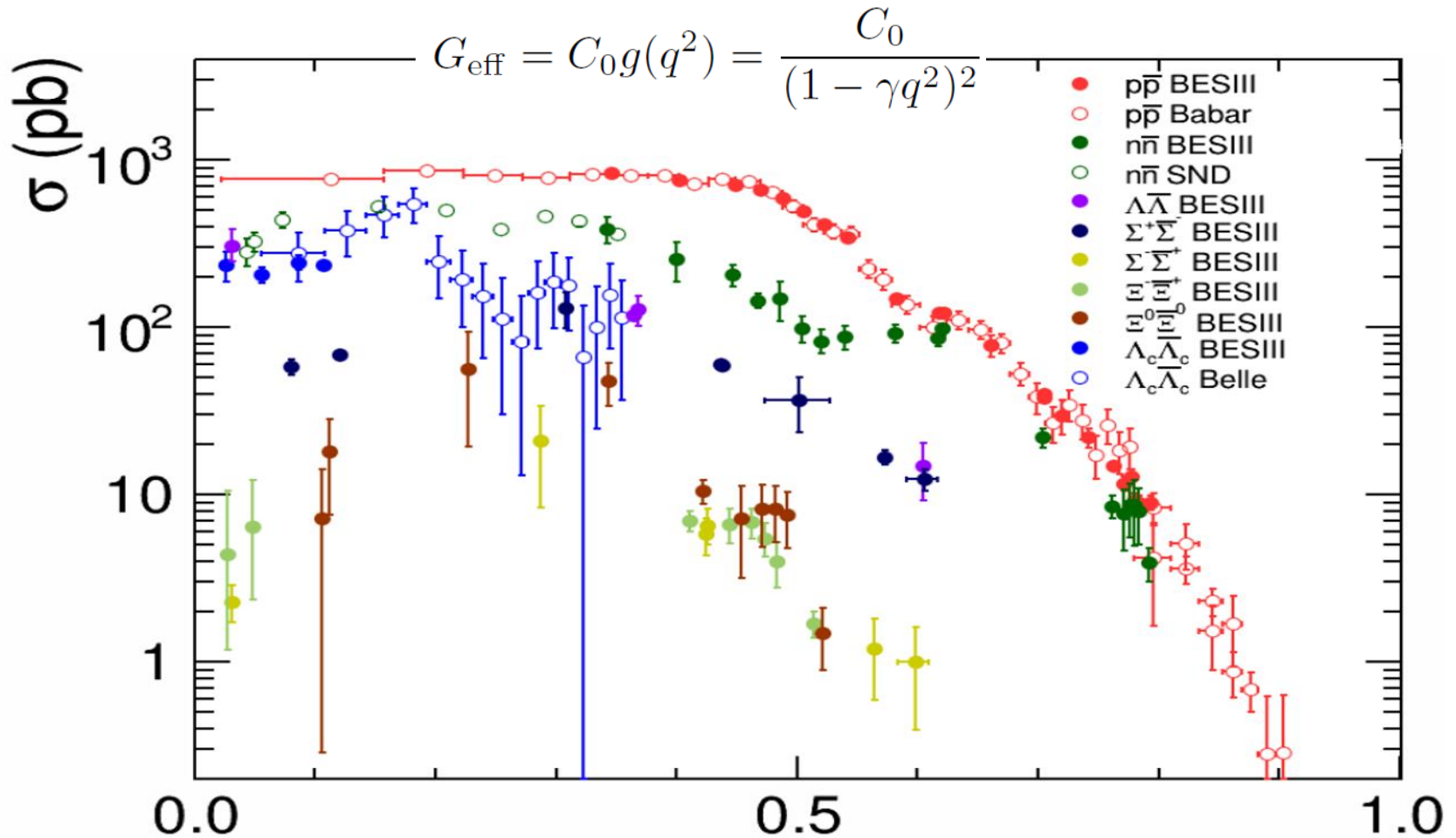
$$m_{1^{\Xi\Xi}^-} = 2.79 \pm 0.11 \text{ GeV}$$

PRD.105.034011 (2022)

PRD.105.014016 (2022)



Dipole behavior of baryon effective form factors



National Science Review 8, nwab187 (2021)

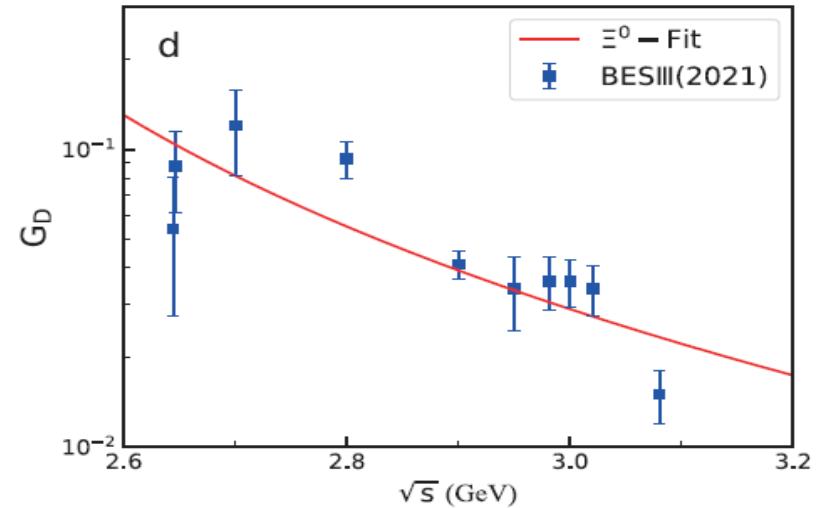
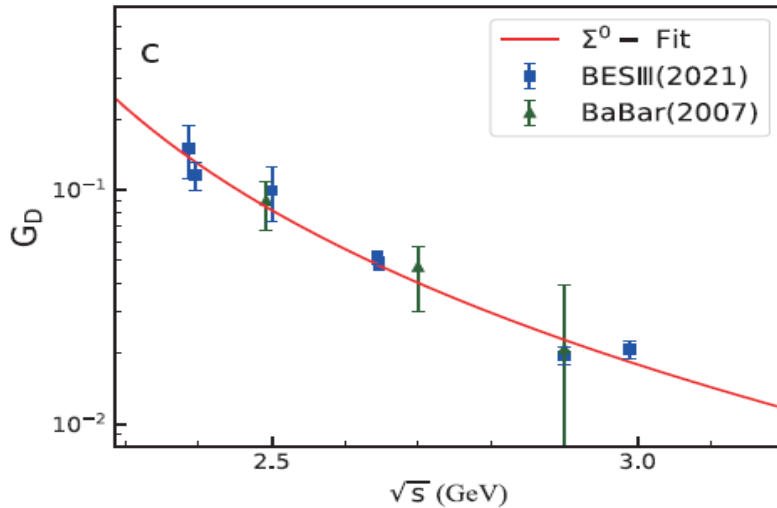
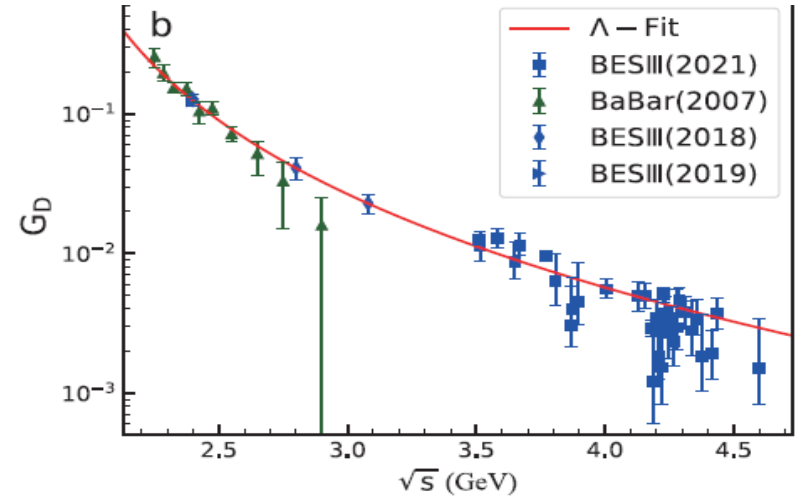
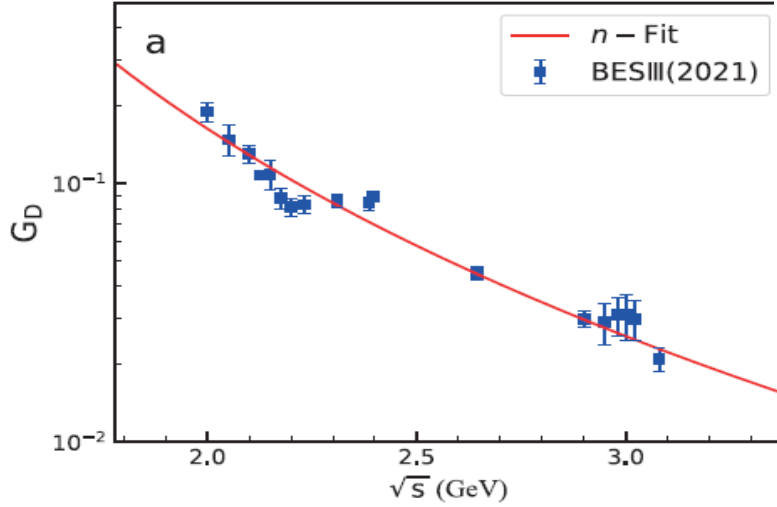
2022.8.22, Lanzhou

G.S. Huang: BESIII QCD

$$\beta = \sqrt{1 - 4M_B^2/s}$$

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

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).

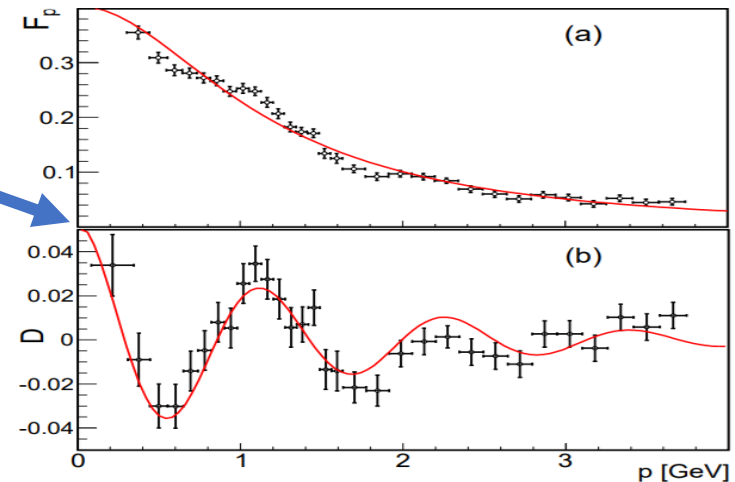
“Oscillation” of baryon effective form factors

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

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

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

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

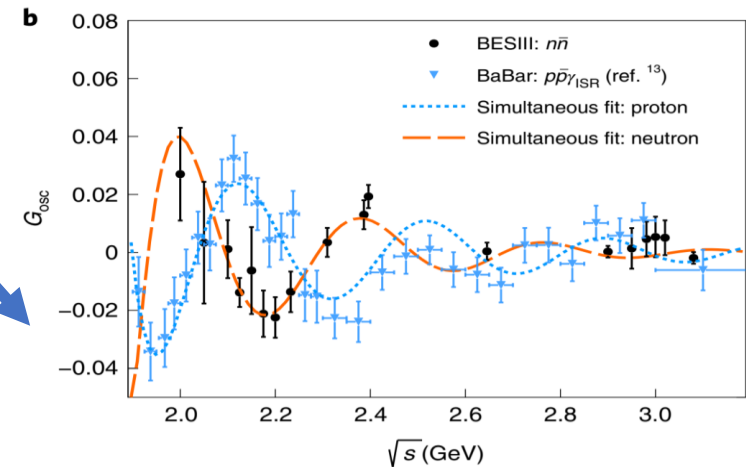


2021, BESIII Collaboration, *Nature Phys.*, 2021,
17(11): 1200-1204.

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

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

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



New parametrization for the “oscillation”

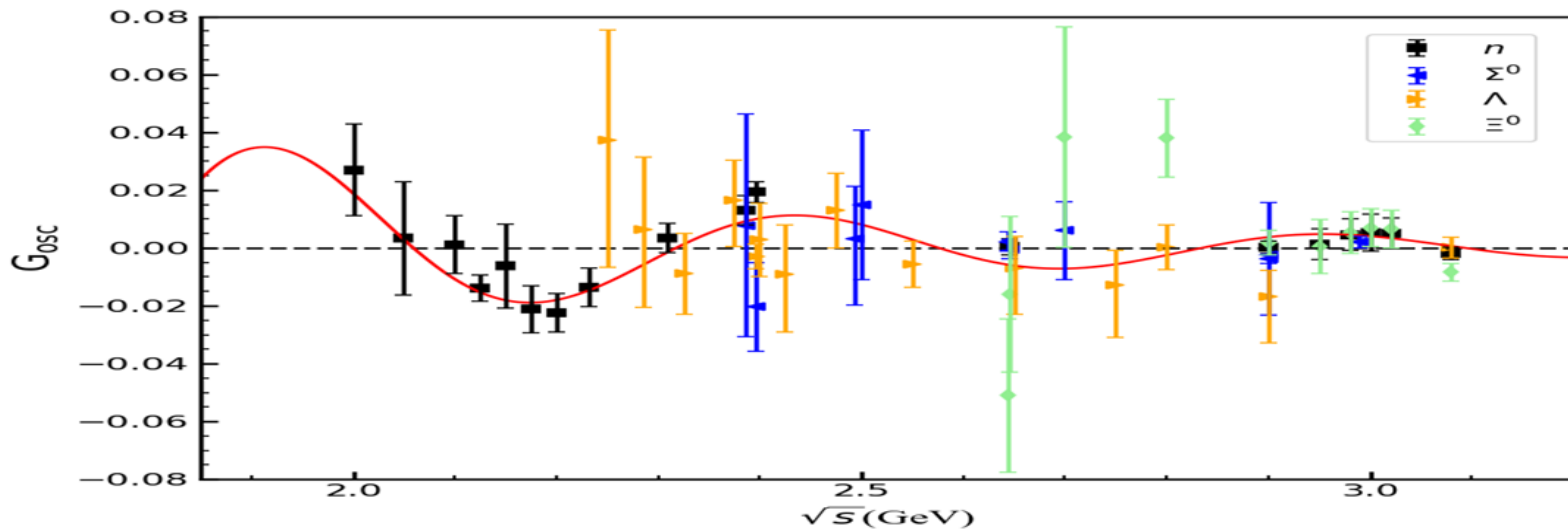
$$G_D(q^2) = \frac{c_0}{(1 - \gamma q^2)^2} \quad G_{osc} = A \cdot \frac{c_0}{(1 - \gamma \cdot s)^2} \cdot \cos(C \cdot \sqrt{s} + D)$$

$$G_{eff}(s) = G_D(s) + G_{osc}(s)$$

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

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

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



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>

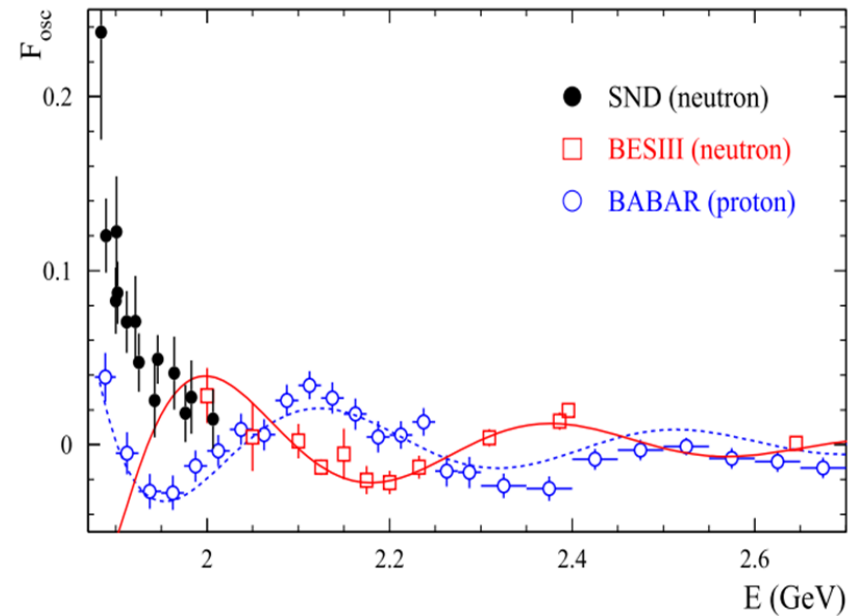
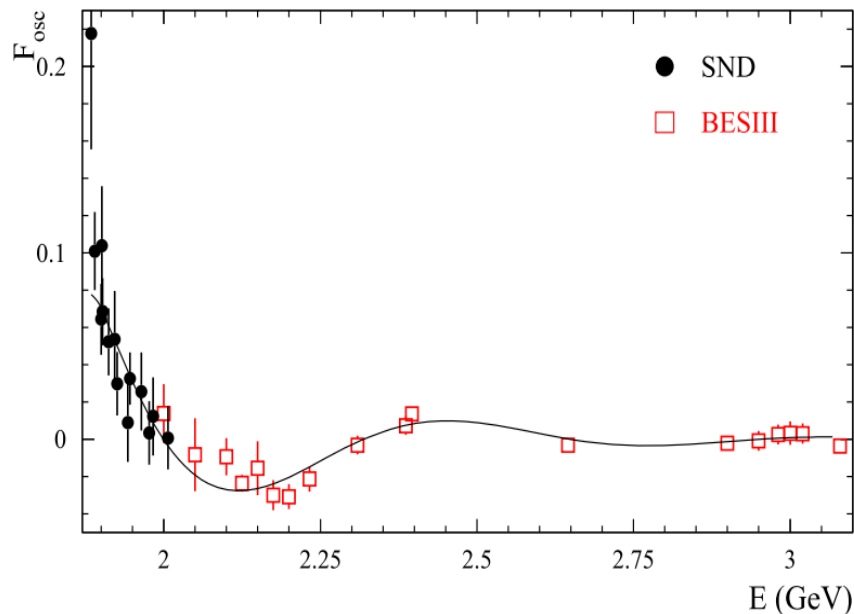
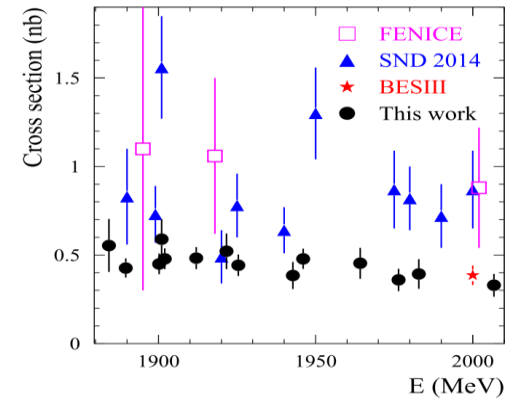
THE EUROPEAN
PHYSICAL JOURNAL C



Regular Article - Experimental Physics

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

SND Collaboration

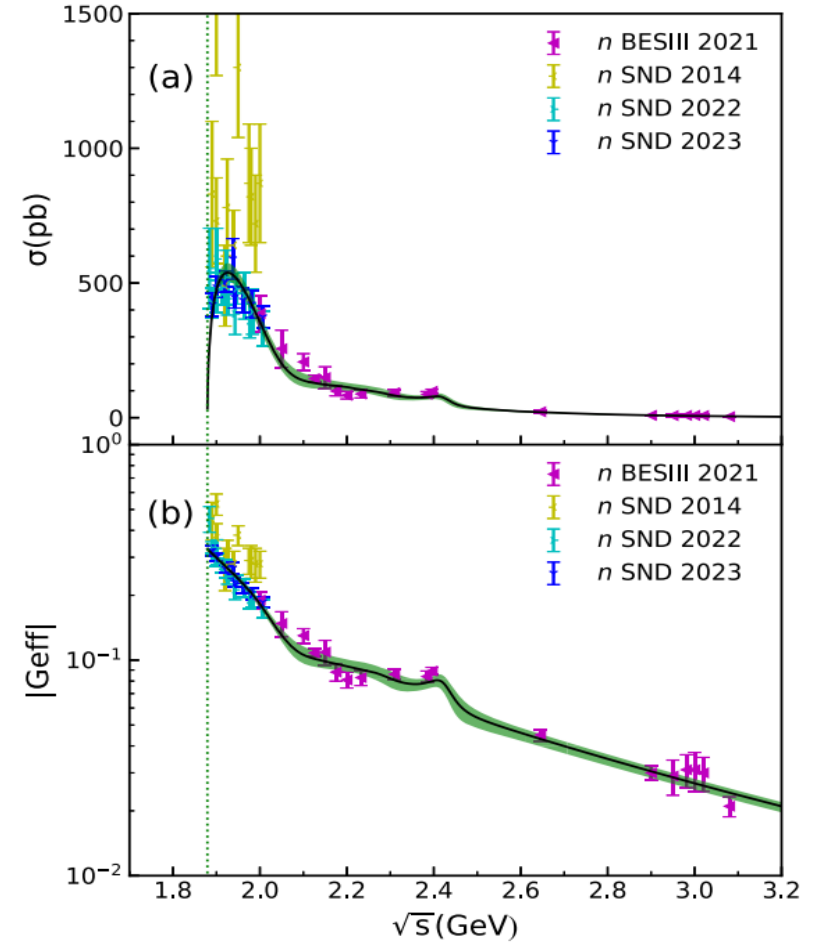
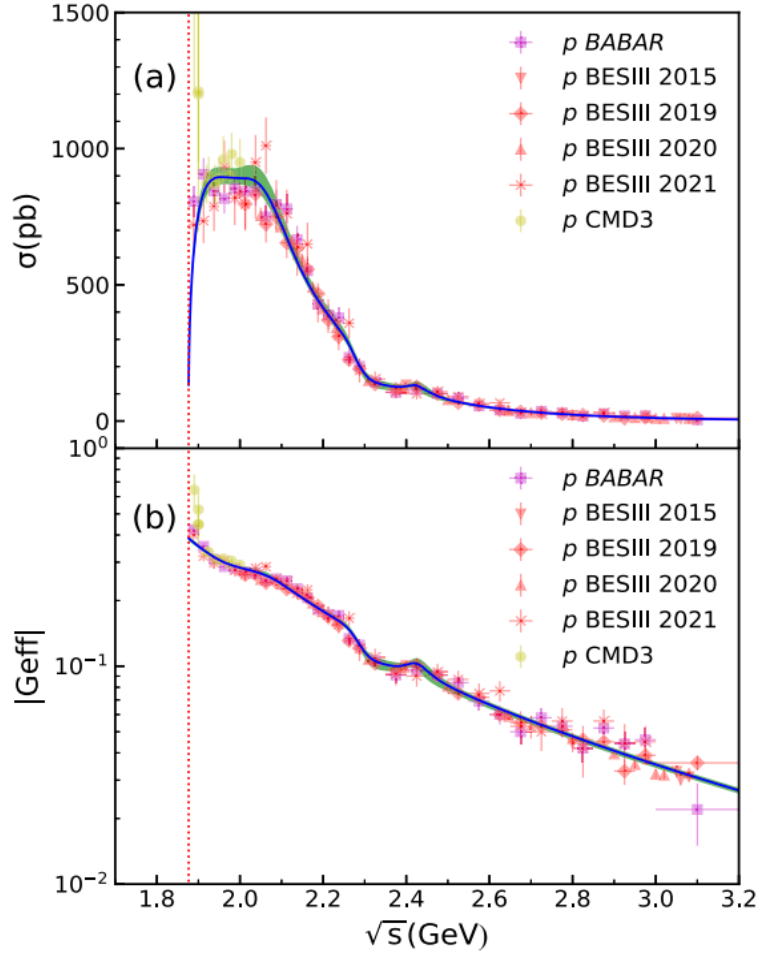


EMFFs of proton and neutron (VMD)

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

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

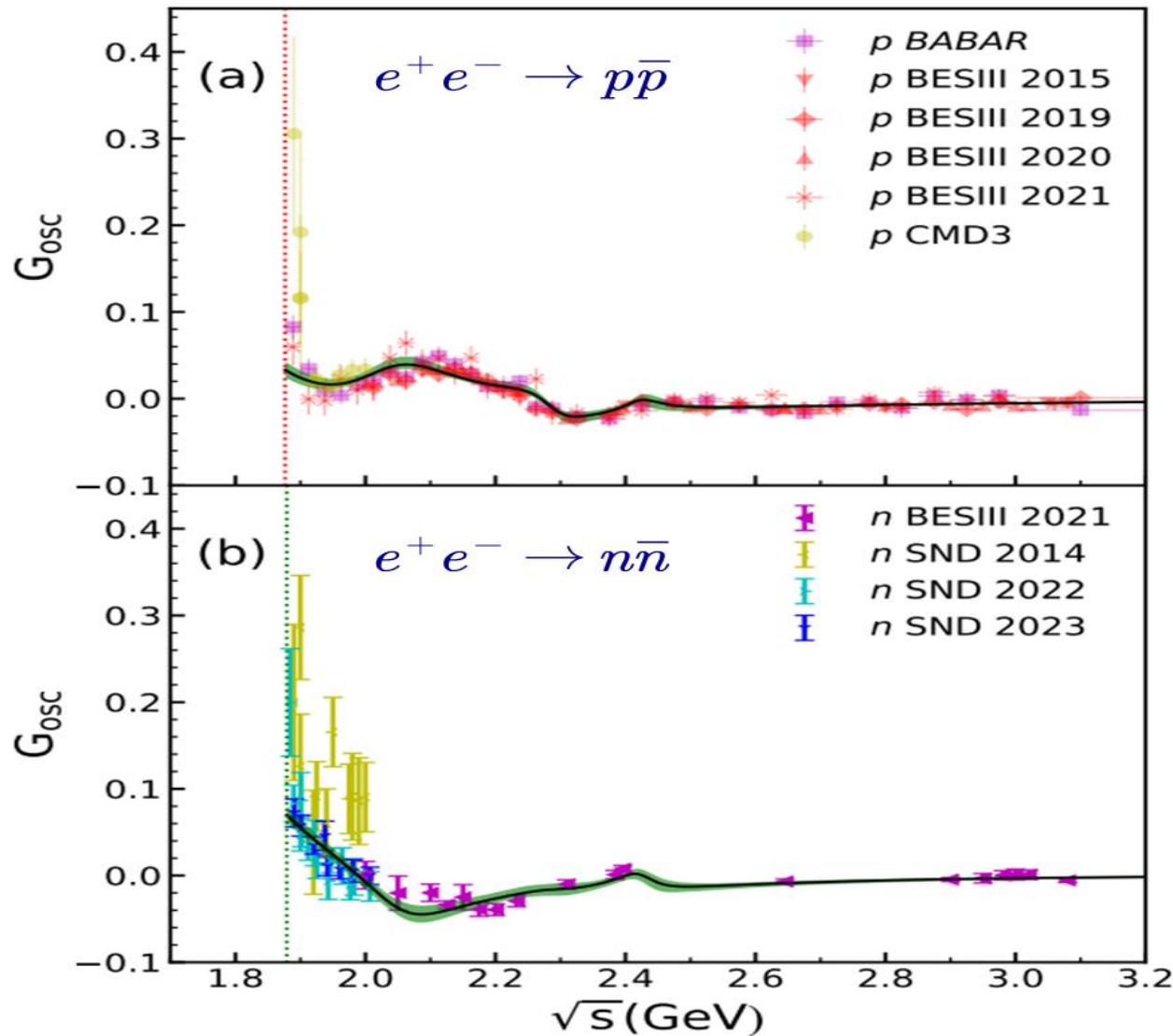
$$e^+e^- \rightarrow n\bar{n}$$



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

$$G_{\text{osc}} = |G_{\text{eff}}| - G_D = |G_{\text{eff}}| - \frac{c_0}{(1 - \gamma_S)^2}$$

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

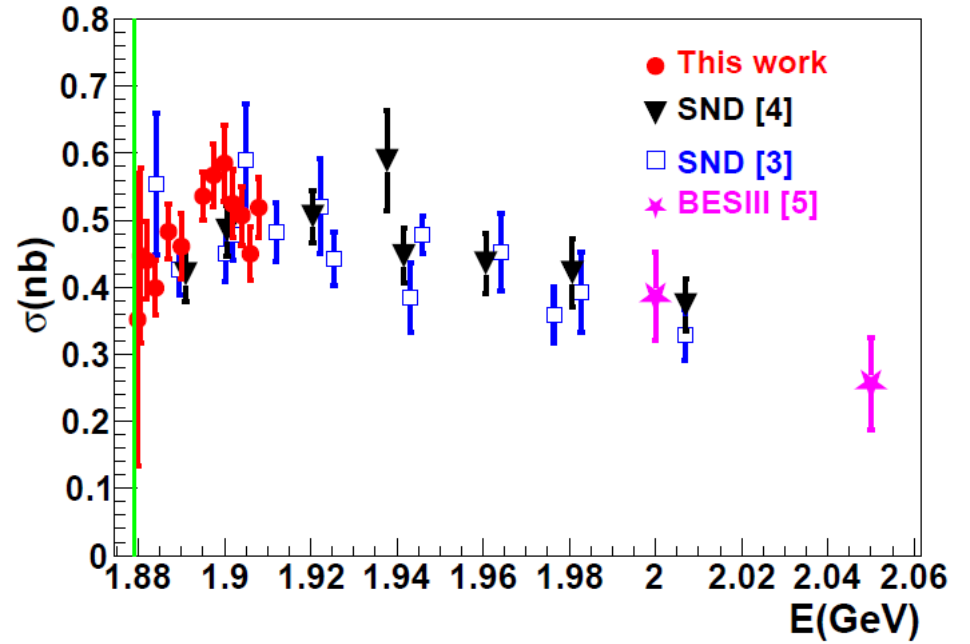
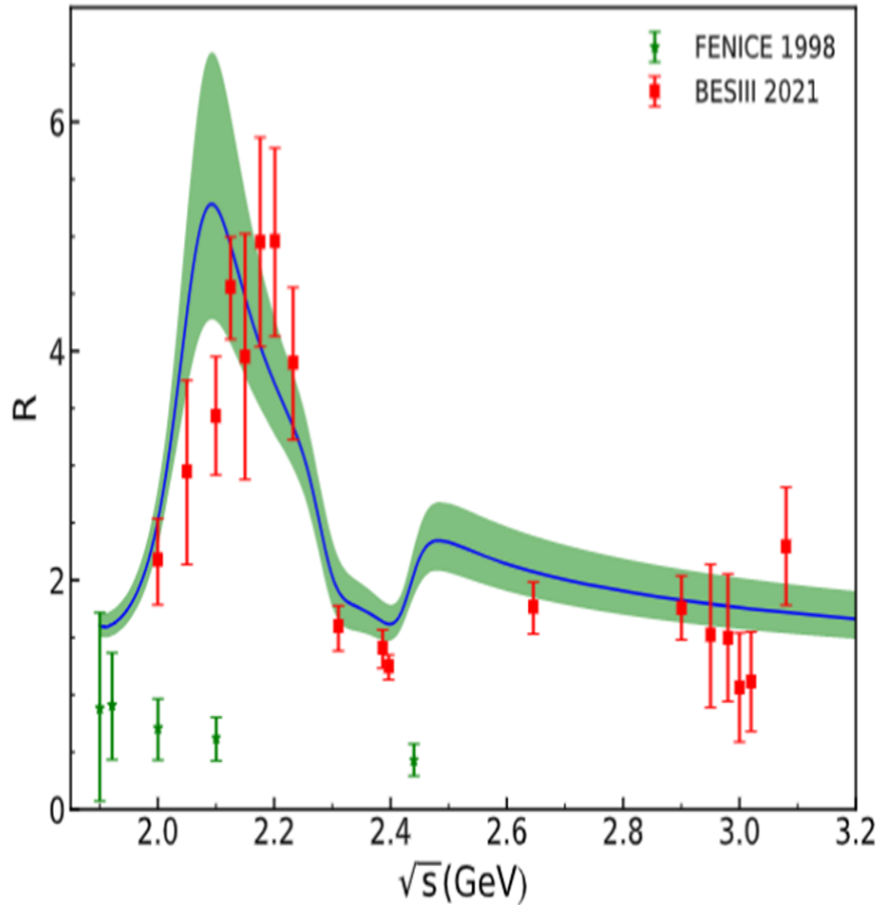


$c_0 = 5.54 \pm 0.02$
for proton

$c_0 = 4.08 \pm 0.04$
for neutron

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

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



arXiv:2407.15308v1 [hep-ex]

Summary

1、 Threshold enhancement

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

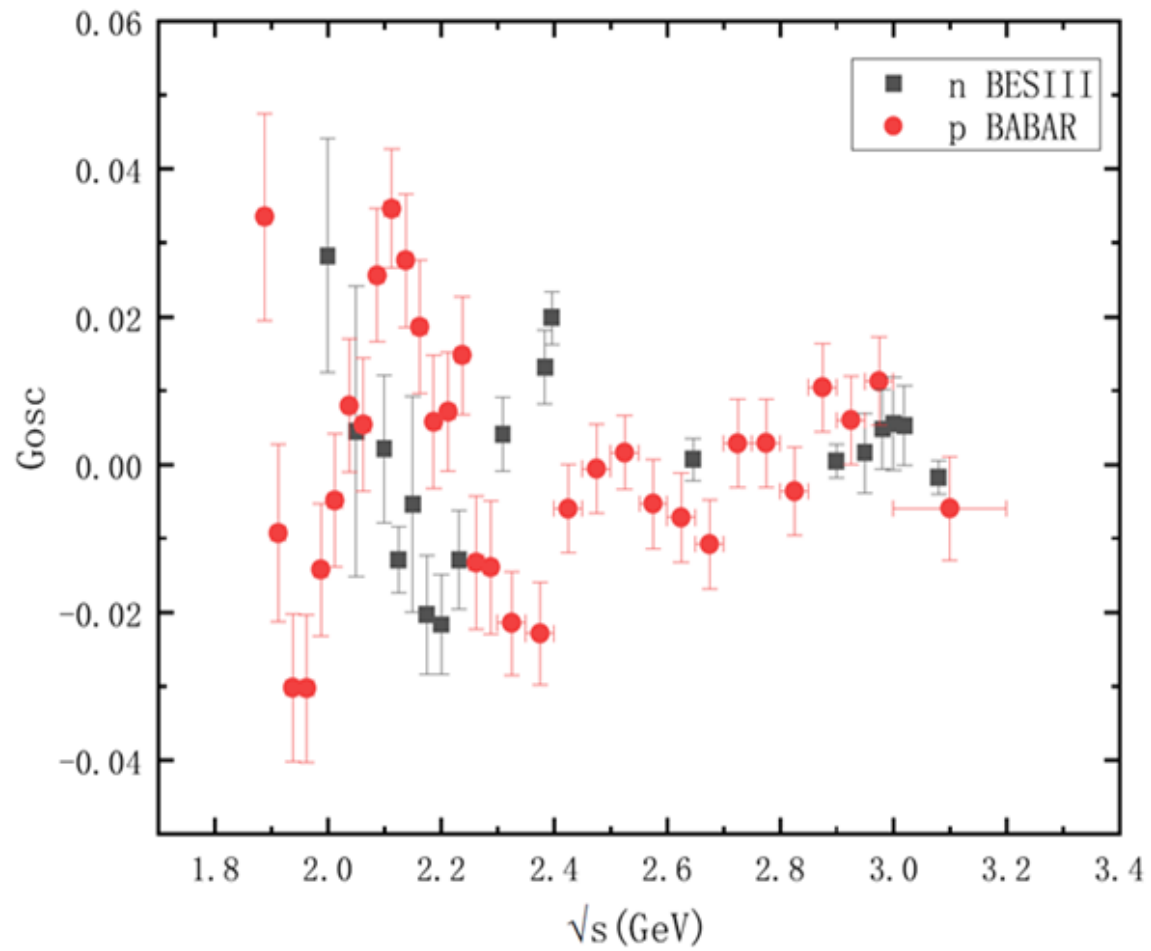
2、 “Oscillation” of baryon effective form factors

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

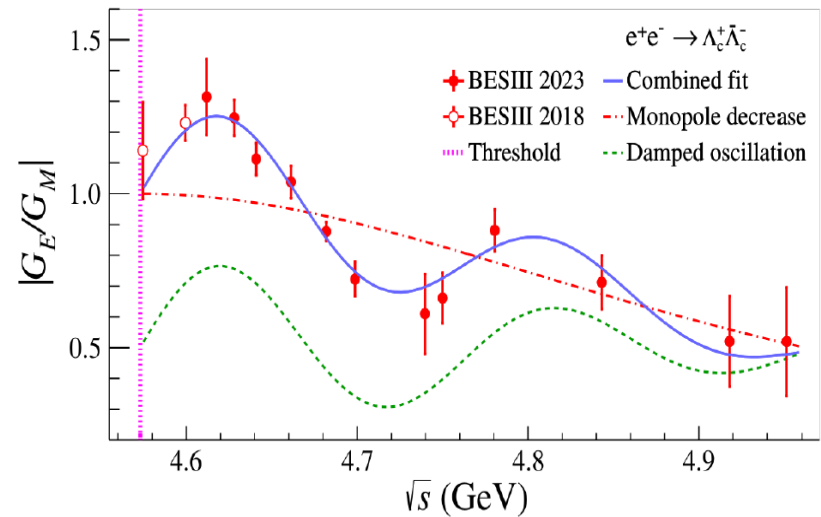
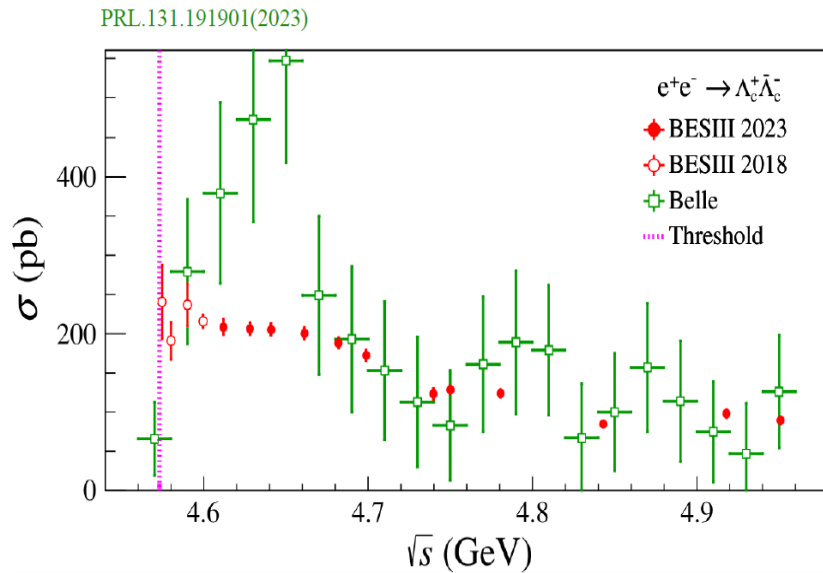

$$g(q^2) = \frac{1}{(1 - \gamma q^2)^2}$$

we conclude that the non-monotonic structures observed in the line shape of the $e^+e^- \rightarrow B\bar{B}$ total cross sections can be naturally explained within the vector meson dominance model. Additionally, the $e^+e^- \rightarrow B\bar{B}$ reactions can be used to study the excited vector states, especially for those exotic states that couple strongly to the $B\bar{B}$ channels.

Thank you very much for your attention!



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

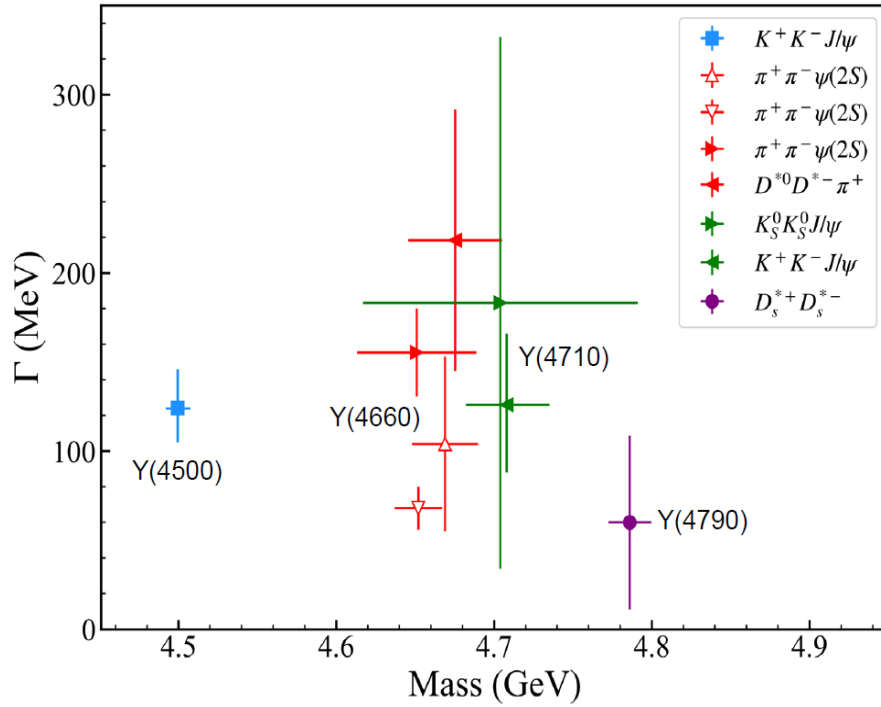


The results of BESIII revealed that there is no peak around $\sqrt{s} = 4.63$ GeV but a long flat from the threshold to 4.68 GeV, diverging from the Belle measurements

The threshold enhancement

The long plateau figure is about 90 MeV

The oscillation behavior of the ratio



$\triangle$: BABAR ∇ : Belle Others: BESIII

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

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

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

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

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

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

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

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

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

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

