Σ and Ξ electromagnetic form factors in the extended vector meson dominance model

闫冰

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第六届强子谱和强子结构研讨会

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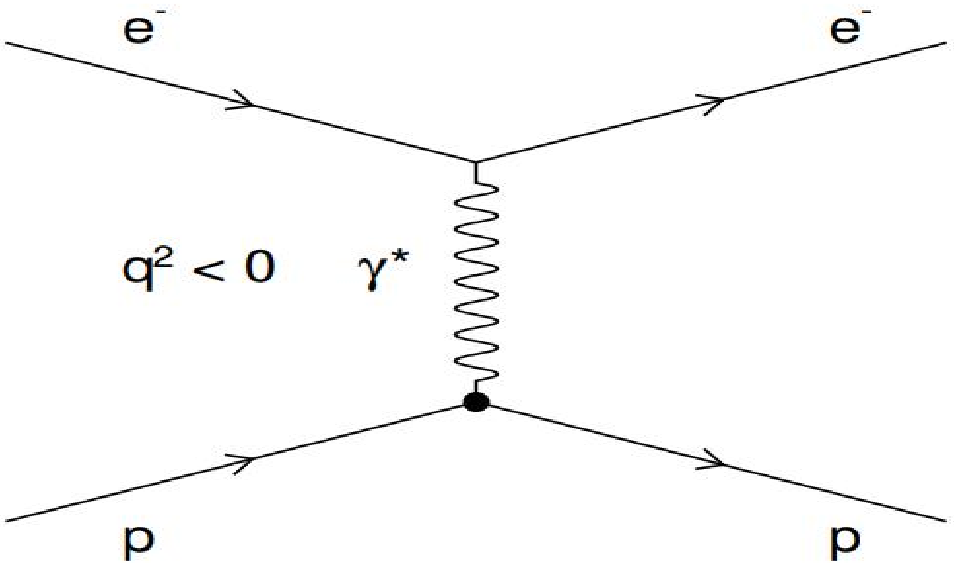
目录

CONTENT

01

引言

电磁形状因子

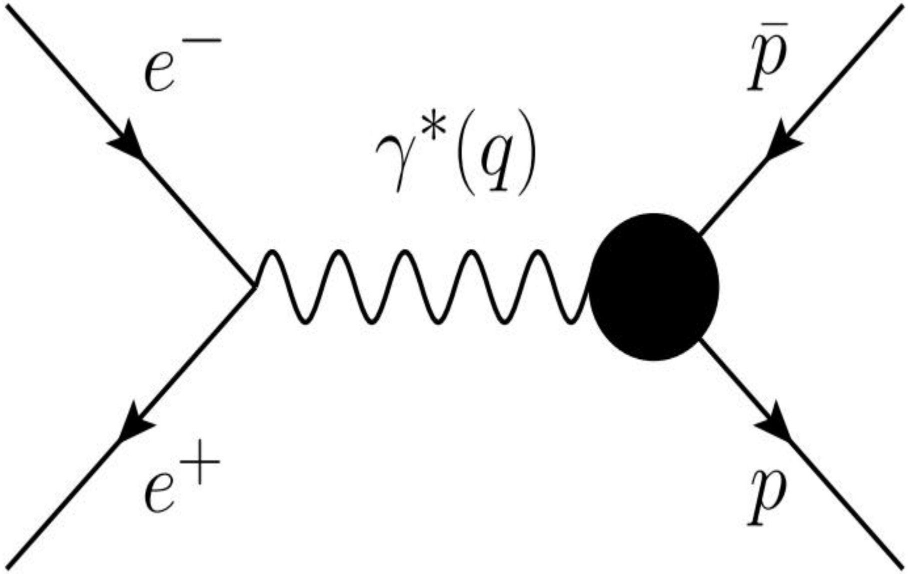


$$e(k)+p(p)\rightarrow e(k')+p(p')$$

ep散射中核子的电磁流：
$$J^{\mu}=\bar{u}(p')[\gamma_{\mu}F_1(q^2)+\frac{i\sigma_{\mu\nu}q^{\nu}}{2m_{\mathrm{p}}}F_2(q^2)]u(p)$$

$$G_E=F_1(q^2)+\tau\cdot F_2(q^2)\qquad G_M=F_1(q^2)+F_2(q^2)\qquad \tau=\frac{q^2}{4m_p^2}$$

重子对产生（类时）



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

微分散射截面：

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

总截面:

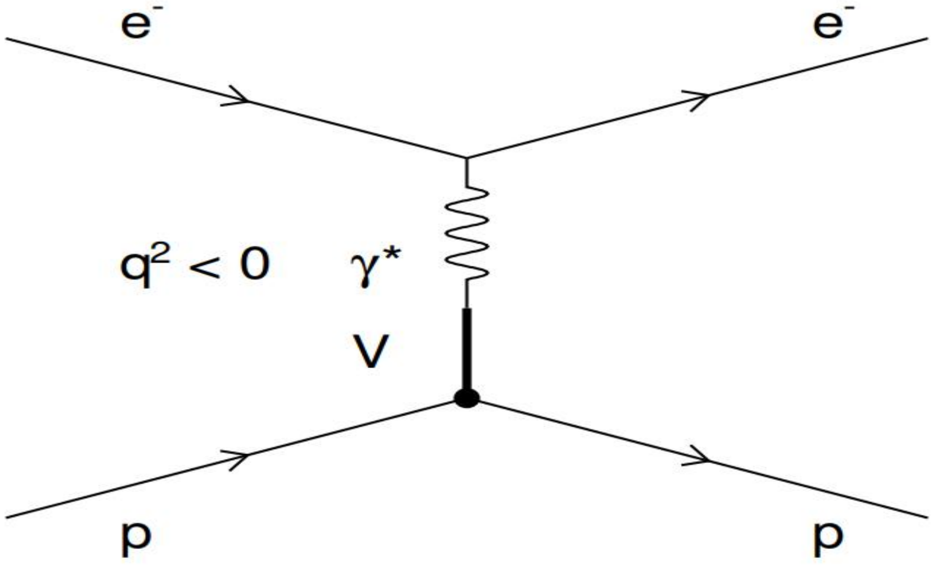
$$\sigma_{e^+e^-\to p\bar{p}}(s) = \frac{4\pi\alpha^2\beta C}{3s}\left[\left|G_M(s)\right|^2+\frac{\left|G_E(s)\right|^2}{2\tau}\right]$$

有效形状因子:

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

矢量介子主导模型

$$iM=\overline{\mu}(k')(-ie\gamma^{\upsilon})\mu(k)\left(\frac{-ig_{\mu\upsilon}}{q^2}\right)\times\overline{u}_{s'}(p')(ie)\left\{-\left(\frac{p'^{\mu}+p^{\mu}}{2M_p}\right)F_2(q^2)+\gamma^{\mu}\left[F_1(q^2)+F_2(q^2)\right]\right\}u_s(p)$$



$$L_{BBV}=g\overline{\psi}\gamma_{\mu}\psi\varphi_V^{\mu}+\frac{\kappa}{4m}\overline{\psi}\sigma_{\mu\upsilon}\psi(\partial^{\mu}\varphi_V^{\upsilon}-\partial^{\upsilon}\varphi_V^{\mu})$$

$$e(k)+p(p)\rightarrow e(k')+p(p')$$

$$iM=\overline{\mu}(k')(-ie\gamma^{\upsilon})\mu(k)\left(\frac{-ig_{\mu\upsilon}}{q^2}\right)\times\overline{u}_{s'}(p')(ie)\left\{-\left(\frac{p'^{\mu}+p^{\mu}}{2M_p}\right)\frac{\kappa}{f_V}\frac{m_V^2}{m_V^2-q^2}+\gamma^{\mu}\left[\frac{g}{f_V}\frac{m_V^2}{m_V^2-q^2}+\frac{\kappa}{f_V}\frac{m_V^2}{m_V^2-q^2}\right]\right\}u_s(p)$$

$$F_1(q^2) = \frac{g}{f_V}\frac{m_V^2}{m_V^2 - q^2};$$

$$\frac{g}{f_V} \to \beta$$

$$F_1(q^2) = \sum_i \beta \frac{m_V^2}{m_V^2 - q^2};$$

$$F_2(q^2) = \frac{\kappa}{f_V}\frac{m_V^2}{m_V^2 - q^2};$$

$$\frac{\kappa}{f_V} \to \alpha$$

$$F_2(q^2) = \sum_i \alpha \frac{m_V^2}{m_V^2 - q^2};$$

g(t)	P	$\chi^2(\Gamma_\rho = 0)$	$\chi^2(\Gamma_\rho = 112\mathrm{MeV})$
$(1-\gamma t)^{-1}$	3	8.79	2.63
	5	1.75	1.40
$(1-\gamma t)^{-2}$	3	3.00	0.945
	5	1.79	0.924
Eikonal,eq.	3	9.36	1.80
	5	1.65	1.08

F. Iachello, A. D. Jackson, and A. Lande, Phys. Lett. B 43B, 191 (1973).

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

$$F_1(q^2) = g(q^2)\left(\sum_i \beta \frac{m_V^2}{m_V^2 - q^2}\right);$$

$$F_2(q^2) = g(q^2)\left(\sum_i \alpha \frac{m_V^2}{m_V^2 - q^2}\right);$$

02

Σ和Ξ形状因子

Σ形状因子

通过同位旋分解同时描述Σ同位旋三重态的形状因子

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

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

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

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

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

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

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

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

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

$$B_i = \frac{m_i^2}{m_i^2 - q^2 - i m_i \Gamma_i}, i = \rho, \omega\phi$$

通过q²=0时电磁形状因子的约束行为

$$G_E^{\Sigma^+} = 1, \quad G_M^{\Sigma^+} = \mu_{\Sigma^+};$$

$$G_E^{\Sigma^-} = -1, \quad G_M^{\Sigma^-} = \mu_{\Sigma^-};$$

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

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

三形状因子

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

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

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

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

$$B_i=\frac{m_i^2}{m_i^2-q^2-im_i\Gamma_i},i=\rho,\omega\phi,V_1,V_2$$

$$G_E^{\Xi^-}=-1,G_M^{\Xi^-}=\mu_{\Xi^-};G_E^{\Xi^0}=0,G_M^{\Xi^0}=\mu_{\Xi^0}$$

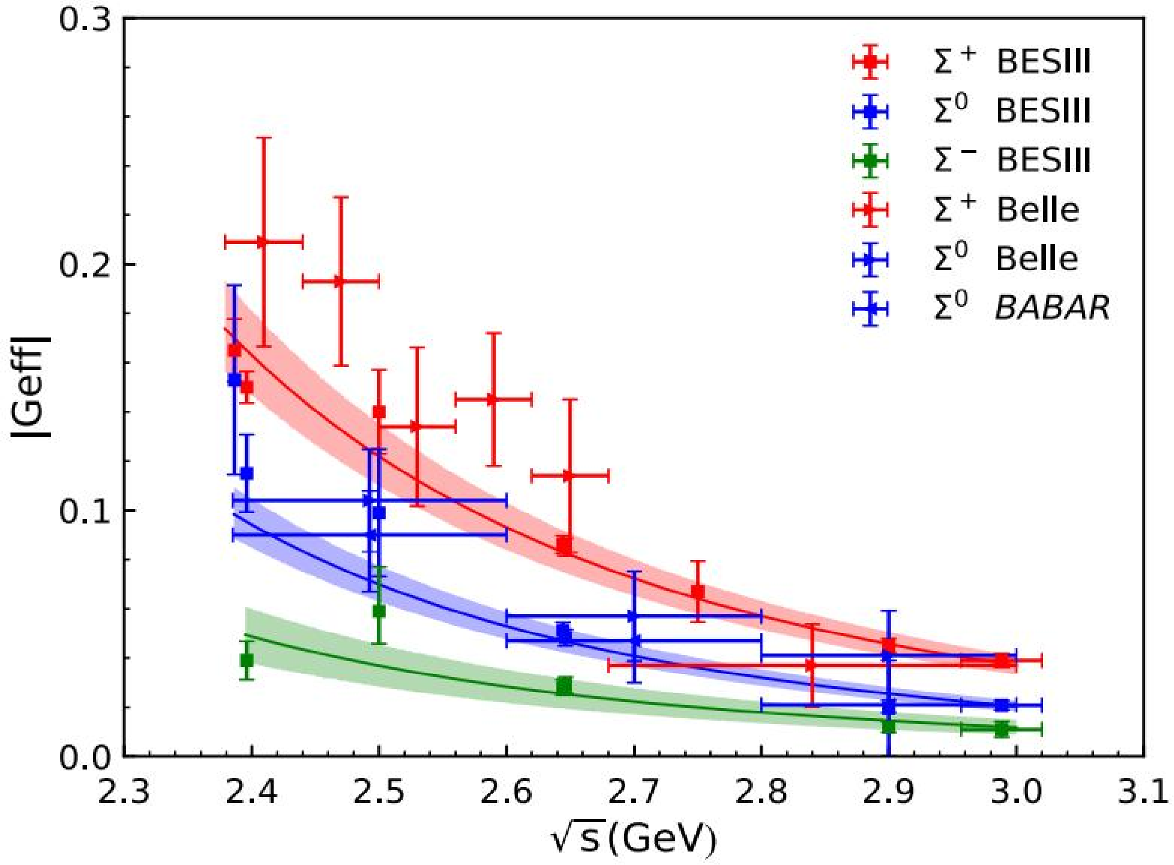
$$f_1^{\Xi^-}=-1+\frac{\beta_\rho}{\sqrt{2}}+\frac{\beta_{V_1}}{\sqrt{2}}+\frac{\beta_{V_2}}{\sqrt{2}}-\frac{\beta_{\omega\phi}}{\sqrt{2}},$$

$$f_2^{\Xi^-}=\mu_{\Xi^-}+1+\frac{\alpha_{V_1}}{\sqrt{2}}+\frac{\alpha_{V_2}}{\sqrt{2}}-\frac{\alpha_{\omega\phi}}{\sqrt{2}};$$

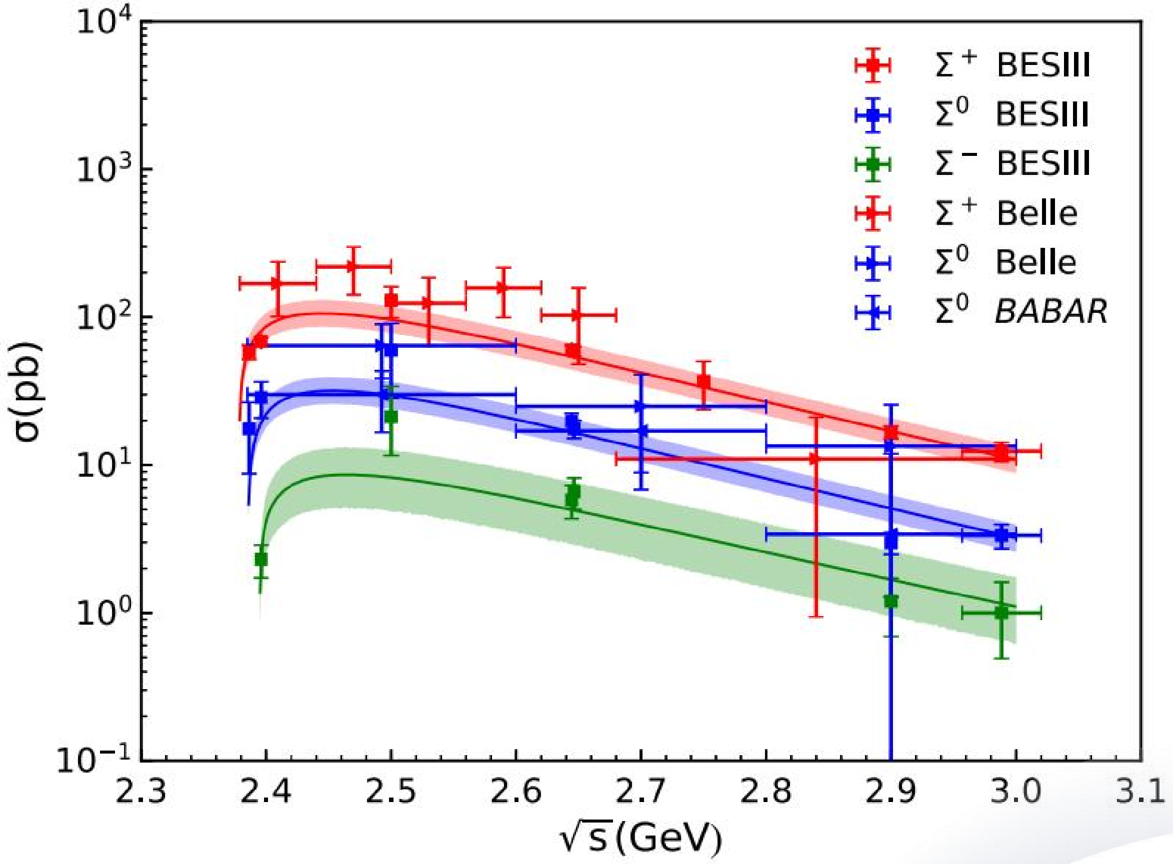
$$f_1^{\Xi^0}=-\frac{\beta_\rho}{\sqrt{2}}-\frac{\beta_{V_1}}{\sqrt{2}}-\frac{\beta_{V_2}}{\sqrt{2}}-\frac{\beta_{\omega\phi}}{\sqrt{2}},$$

$$f_2^{\Xi^0}=\mu_{\Xi^0}-\frac{\alpha_{V_1}}{\sqrt{2}}-\frac{\alpha_{V_2}}{\sqrt{2}}-\frac{\alpha_{\omega\phi}}{\sqrt{2}};$$

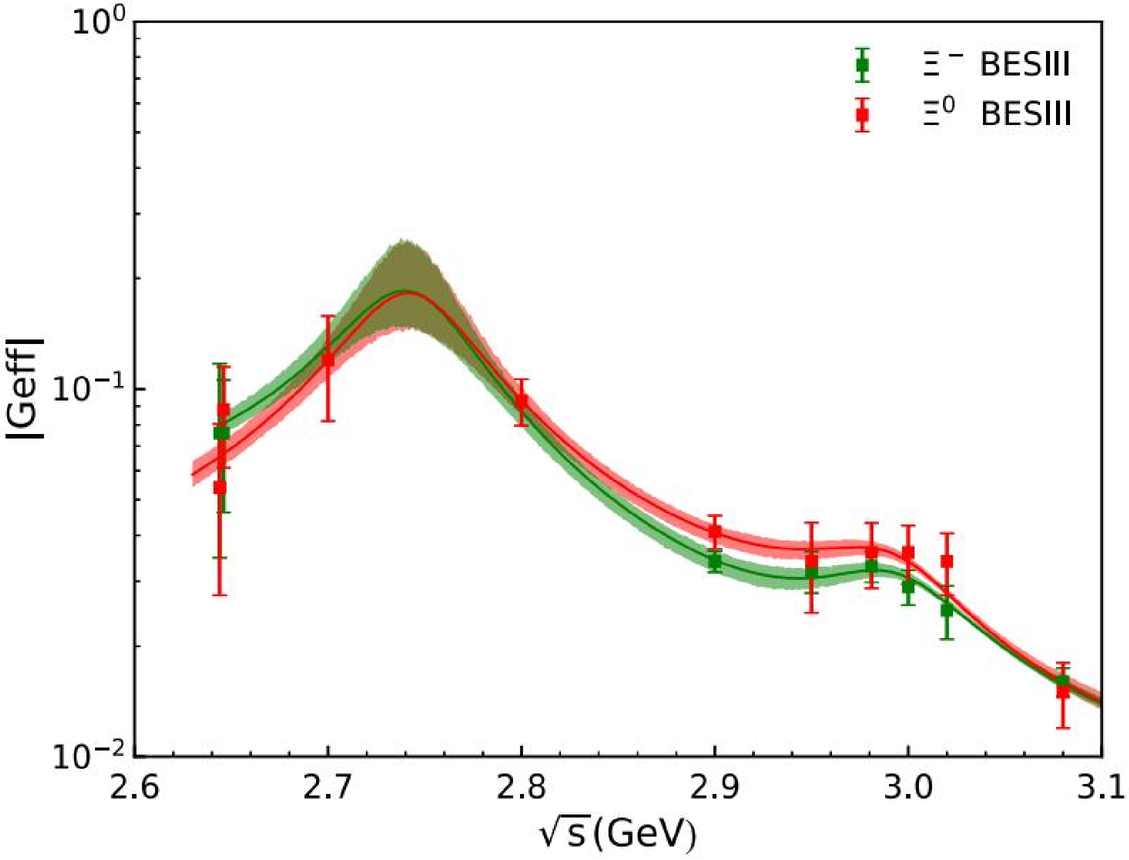
拟合结果



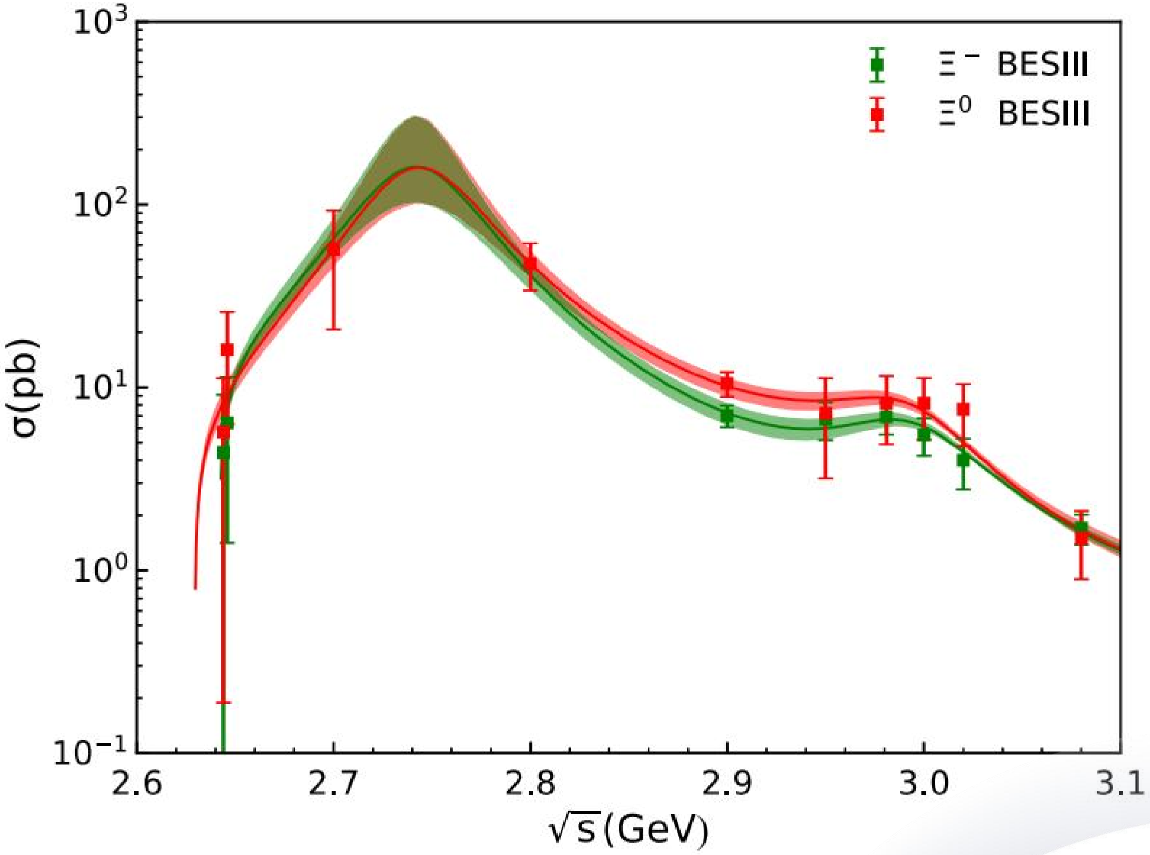
Σ超子有效形状因子结果



Σ超子反应总截面结果



Ξ超子有效形状因子结果



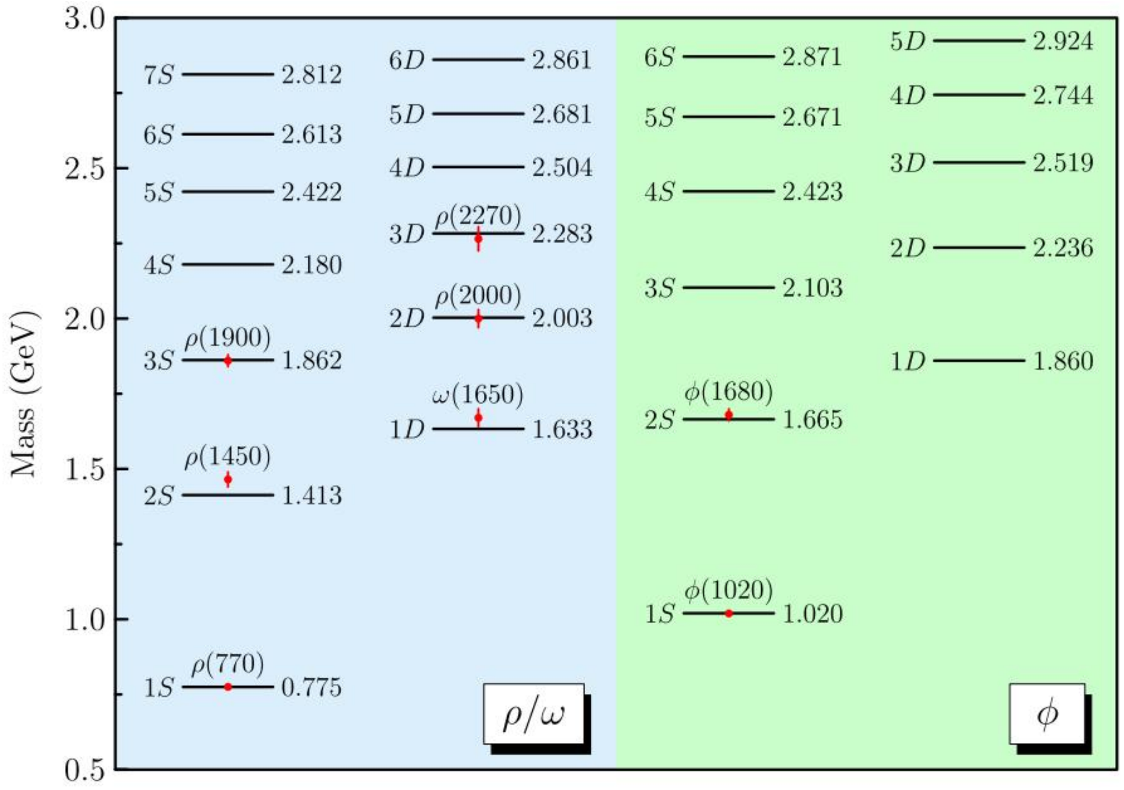
Ξ超子反应总截面结果

Σ超子拟合参数

γ (GeV^{-2})	β_ρ	$\beta_{\omega\varphi}$	$\alpha_{\omega\varphi}$	χ^2/dof
0.527±0.024	1.63±0.07	-0.08±0.06	-3.18±0.77	1.69

Ξ超子拟合参数

β_ρ	$\beta_{\omega\varphi}$	β_{V1}	β_{V2}	m_{V1} (GeV)
0.616±0.024	-0.774±0.023	0.099±0.003	0.115±0.002	2.742±0.007
$\alpha_{\omega\varphi}$	α_{V1}	α_{V2}	Γ_{V1} (MeV)	χ^2/dof
9.346±0.837	-0.039±0.003	-0.113±0.071	71±28	0.29



Modified Godfrey-Isgur模型计算 ρ、ω、ϕ 高阶态理论结果和实验数据

$$\Gamma_{\phi(4D)} = 128.95 \text{ MeV}$$

L.-M. Wang, S.-Q. Luo, and X. Liu, Phys. Rev. D 105, 034011 (2022).

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

在QCD求和规则框架下Ξ束缚态质量

B.-D. Wan, S.-Q. Zhang, and C.-F. Qiao, Phys. Rev. D 105, 014016 (2022).

03

Σ和Ξ电荷半径

三、Σ超子电磁半径平方均值$\langle r_{ch}^2 \rangle$ (fm²)与其他理论对比

重子	Ξ^0	Ξ^-	Σ^+	Σ^0	Σ^-
This Work	-0.04±0.01	0.58±0.01	0.80±0.02	0.10±0.01	0.70±0.02
ChPT[1]	0.13±0.03	0.49±0.05	0.60±0.02	-0.03±0.01	0.67±0.03
ChPT[2]	0.36±0.02	0.61±0.01	0.99±0.03	0.10±0.02	0.780
ChET[3]	-0.015±0.007	0.601±0.127	0.719±0.116	0.010±0.004	0.700±0.124
ChCQM[4]	0.091	0.587	0.825	0.089	0.643

$$\langle r_{ch}^2 \rangle = \begin{cases} \dfrac{-6}{G_E(0)} \dfrac{dG_E(Q^2)}{dQ^2}\Big|_{Q^2\to 0}, \Sigma^+, \Sigma^-, \Xi^- \\ -6\dfrac{dG_E(Q^2)}{dQ^2}\Big|_{Q^2\to 0}, \Sigma^0, \Xi^0 \end{cases}$$

$$\langle r_{ch}^2 \rangle = 0.61 \pm 0.12 \pm 0.09 \text{ fm}^2$$

Phys. Lett. B 522, 233 (2001),(SELEX Collaboration).

$$\langle r_{ch}^2 \rangle = 0.91 \pm 0.32 \pm 0.4 \text{ fm}^2$$

Eur. Phys. J. C 8, 59 (1999),(WA89 Collaboration).

[1] B. Kubis and U. G. Meissner, Eur. Phys. J. C 18, 747 (2001).
[2] A. N. Hiller Blin, Phys. Rev. D 96, 093008 (2017).
[3] M. Yang and P. Wang, Phys. Rev. D 102, 056024 (2020).
[4] G. Wagner, A. J. Buchmann, and A. Faessler, Phys. Rev. C 58, 3666 (1998).

04

总结

1.我们通过引入同位旋分解对Σ 同位旋三重态和 Ξ 同位旋二重态以同样的参数γ，分别拟合得到耦合常数描述了其有效形状因子和反应总截面的结果，并且成功再现了反应 $e^{+}e^{-}\rightarrow\Sigma^{+}\overline{\Sigma}^{-},\Sigma^{0}\overline{\Sigma}^{0},\Sigma^{-}\overline{\Sigma}^{+}$ 总截面的比率9.7±1.3:3.3±0.7:1。

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

2.在对 Ξ 拟合时引入了两个共振，其一质量为2742±7MeV，宽度为71±28MeV；另一共振结构为BESIII合作组对 Ξ^{-}截面拟合所得，质量为2993±28MeV，宽度为88±79MeV。

3.将模型返回到类空，得到Σ同位旋三重态和 Ξ 同位旋二重态的电荷半径平方均值，其中Σ^{-}的结果在误差范围内和两个实验数据一致。

感谢您的倾听，
期待您的批评与建议！