

用自旋观测量研究强子谱中的近阈值结构

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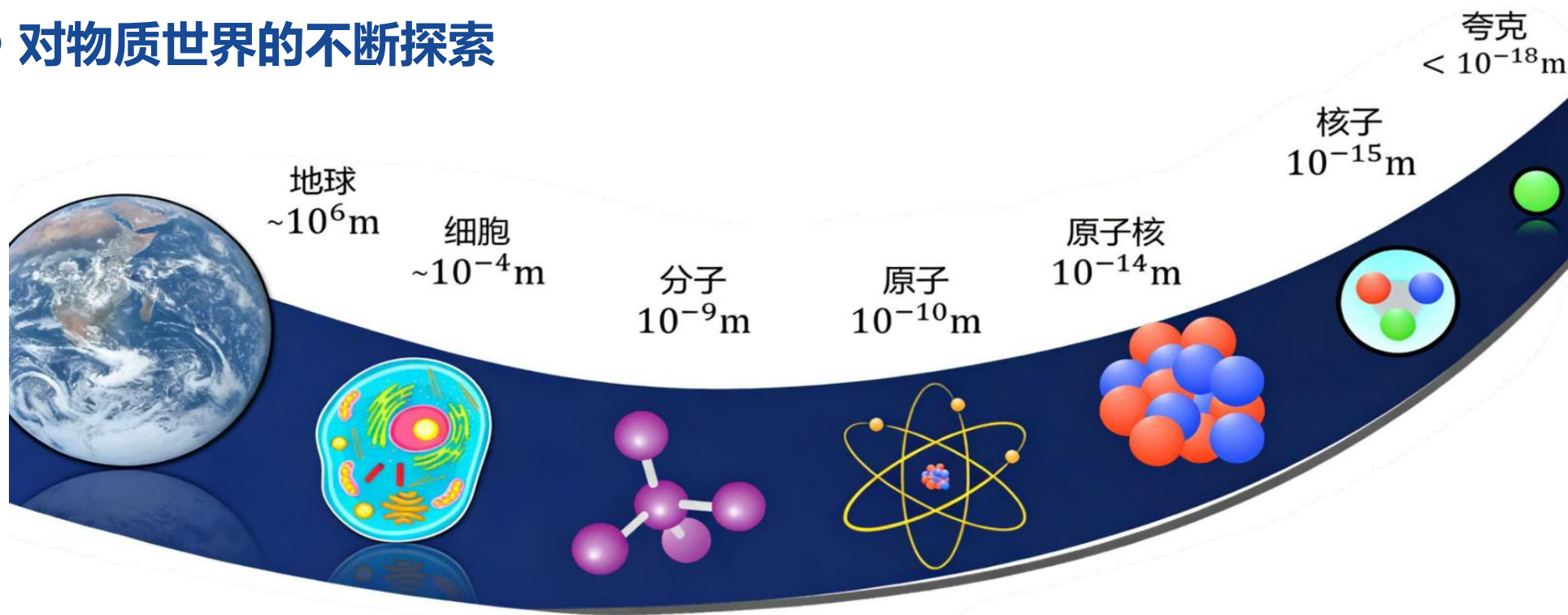
2026.02.04

用自旋观测量研究强子谱中的近阈值结构

● 报告题目分析

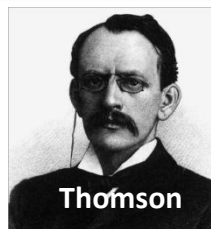
- 自旋观测量→研究工具
- 强子谱中的结构→研究对象
- 什么是强子？什么是强子谱？

● 对物质世界的不断探索

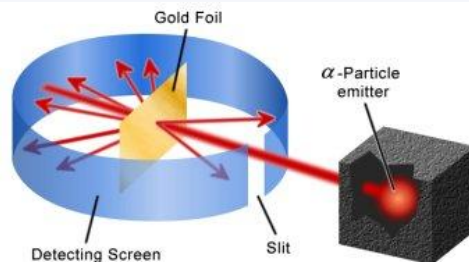


对亚原子结构探索的回顾

• 电子



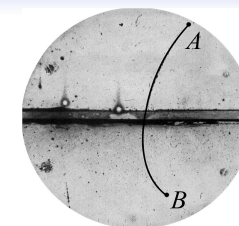
1906



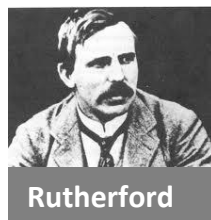
• 正电子



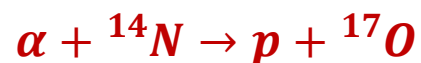
1936



• 质子



1908



• 预言 π 介子



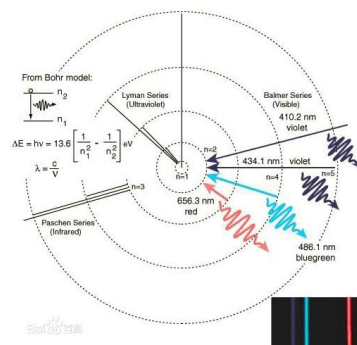
1949

$$V(r) = -g^2 \frac{e^{-\mu r}}{r}$$

• Bohr 模型



1922

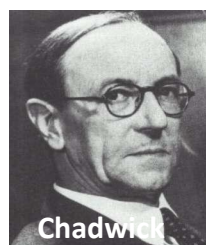


• π 介子



1950

• 中子



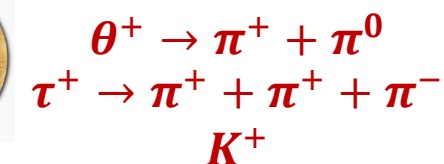
1935



• 宇称破坏

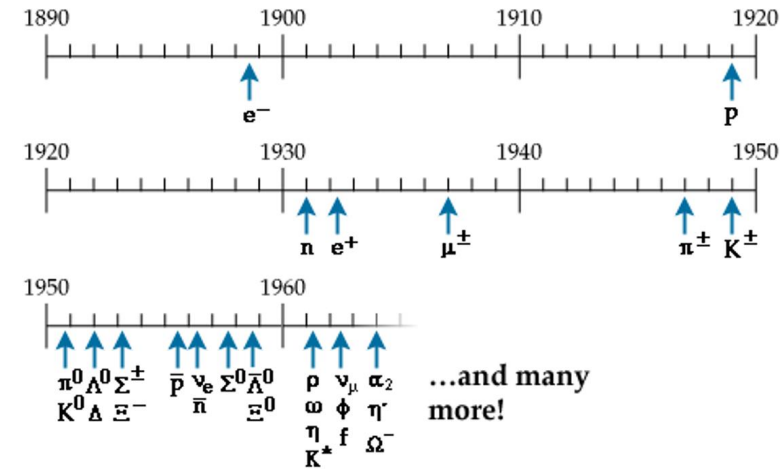


1957



粒子动物园1.0 (Particle Zoo 1.0)

● 1963年的粒子数据表 (Particle Data Group)



- 稳定粒子: $p, n, \Sigma, \Lambda, \Xi; \pi, K; \mu, e, \nu, \dots$
- 介子共振态: $\rho, \omega, K^*, \dots$
- 重子共振态: $\Delta, \Xi^*, \Lambda^*, \Sigma^* \dots$

“两类”粒子:

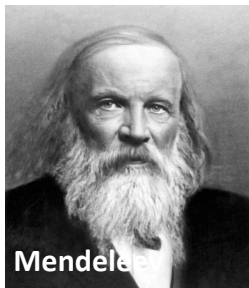
- 非奇异 (Non-strange) : 强子对撞产生, 衰变寿命短 ($\rho, \omega, \Delta \dots$)
- 奇异 (Strange) : 强子对撞产生, 衰变寿命较长 ($K, \Sigma, \Lambda, \Xi, \dots$)

TABLE I. Elementary Particles, March 1963.

Class	Symbol	Charge	Antiparticle	Found	Isospin		Spin	Parity	Strangeness	Mass		Magnetic moment ($e/2m_p$)	Mean life		Common decay modes	Branching ratios (%)	References
					T_1	T_2				(MeV)	(m_p)		(sec)	($1/m_{\tau^2}$)			
Hyperons	Ξ^-	Ξ^+	Ξ^-	Ξ^+	$\frac{1}{2}$	$-\frac{1}{2}$	$\frac{1}{2}$	$-\frac{1}{2}$	$-\frac{1}{2}$	1320.8 ± 0.4	9.46		$1.4 (+0.6/-0.2) \times 10^{-10}$	3×10^{13}	$\Lambda \pi^-$	100	1
	Ξ^0	Ξ^+	Ξ^0	Ξ^+	$\frac{1}{2}$	$-\frac{1}{2}$	$\frac{1}{2}$	$-\frac{1}{2}$	$-\frac{1}{2}$	1316	9.43		$3.9 (+1.4/-0.9) \times 10^{-10}$	8×10^{13}	$\Lambda \pi^0$	100	2
	Ξ^0	Ξ^+	Ξ^0	Ξ^+	$\frac{1}{2}$	$-\frac{1}{2}$	$\frac{1}{2}$	$-\frac{1}{2}$	$-\frac{1}{2}$	1195.96 ± 0.30	8.57		$(1.59 \pm 0.05) \times 10^{-10}$	3.4×10^{13}	$n \pi^-$	100	3, 4, 19
	Ξ^0	Ξ^+	Ξ^0	Ξ^+	$\frac{1}{2}$	$-\frac{1}{2}$	$\frac{1}{2}$	$-\frac{1}{2}$	$-\frac{1}{2}$	1191.5 ± 0.5	8.54		$10^{-11} > \tau > 10^{-22}$	$10^{12} > \tau > 10^{13}$	$\Lambda \gamma$	100	3, 5, 19
Nucleons	Ξ^0	Ξ^+	Ξ^0	Ξ^+	$\frac{1}{2}$	$-\frac{1}{2}$	$\frac{1}{2}$	$-\frac{1}{2}$	$-\frac{1}{2}$	1189.40 ± 0.20	8.52		$(0.78 \pm 0.03) \times 10^{-10}$	1.65×10^{13}	$p \pi^0$ $n \pi^+$	50.7 ± 2.3 49.3 ± 2.3	3, 4, 19
	Λ^0	Λ^0	Λ^0	Λ^0	0	0	$\frac{1}{2}$	$+$	-1	1115.38 ± 0.10	7.991	-1.5 ± 0.5	$(2.57 \pm 0.30) \times 10^{-10}$	5.4×10^{13}	$p \pi^-$ $n \pi^0$	$66(+4/-3)$ $34(+3/-4)$	6, 20
	Λ^0	Λ^0	Λ^0	Λ^0	0	0	$\frac{1}{2}$	$+$	-1	1115.44 ± 0.32	7.991		$(1.9 \pm 1.0) \times 10^{-10}$	4×10^{13}			
	n^0	$\bar{n}$	n^0	$\bar{n}$	$\frac{1}{2}$	$-\frac{1}{2}$	$\frac{1}{2}$	$+$	0	939.567 ± 0.01	6.731	-1.9128	1013 ± 26	2.15×10^{15}	$p e^- \bar{\nu}_e$	100	7, 8
Mesons	p^+	$\bar{p}$	p^+	$\bar{p}$	$\frac{1}{2}$	$-\frac{1}{2}$	$\frac{1}{2}$	$+$	0	938.213 ± 0.01	6.722	2.792816 ± 0.000034 -1.8 ± 1.2	∞	∞			7, 15 10
	K^+	K^-	K^+	K^-	$\frac{1}{2}$	$\frac{1}{2}$	0	$-$	1	493.98 ± 0.14	3.539	0	$(1.227 \pm 0.008) \times 10^{-8}$	2.60×10^{14}	$\mu^+ \nu_\mu (\mu^2)$ $\pi^+ \pi^0 (\pi^2)$ $\mu^+ \pi^0 \nu_\mu (\mu^3)$ $e^+ \pi^0 \nu_e (e^3)$ $\pi^+ \pi^+ \pi^- (\tau^1)$ $\pi^+ \pi^0 \pi^0 (\tau^1')$	64.2 ± 1.3 18.6 ± 0.9 4.8 ± 0.6 5.0 ± 0.5 5.7 ± 0.3 1.7 ± 0.2	9
	K^0	$\bar{K}^0$	K^0	$\bar{K}^0$	$\frac{1}{2}$	$-\frac{1}{2}$	0	$-$	-1	497.9 ± 0.6	3.57	< 0.04 $h e/m_K$	$K_1^0 (0.90 \pm 0.02) \times 10^{-10}$ $K_2^0 6.3(+1.6/-1.0) \times 10^{-8}$	1.9×10^{13} 1.3×10^{16}	$\pi^+ \pi^-$ $\pi^0 \pi^0$ $\pi^+ \pi^- \pi^0$ $3 \pi^0$ $\pi^+ e^- \bar{\nu}_e$ $\pi^- e^+ \nu_e$ $\pi^+ \mu^- \bar{\nu}_\mu$ $\pi^- \mu^+ \nu_\mu$	69.4 ± 1.0 30.6 ± 1.0 8.7 ± 2.3 38 ± 7 28.3 ± 5.9 25.0 ± 5.9	11 12
	π^+	π^-	π^+	π^-	1	$-\frac{1}{2}$	0	$-$	0	139.58 ± 0.05	1	0	$(2.547 \pm 0.027) \times 10^{-8}$	5.48×10^{15}	$\mu^+ \nu_\mu$	100	18
Leptons	π^0	π^0	π^0	π^0	0	0	0	$+$	0	134.97 ± 0.05	0.967	0	$(1.05 \pm 0.18) \times 10^{-16}$	2.23×10^7	2γ $\gamma e^+ e^-$	98.8 1.2	13, 22
	μ^-	μ^+	μ^-	μ^+	$\frac{1}{2}$	$-\frac{1}{2}$	$\frac{1}{2}$	$+$		105.65	206.765 ± 0.002 m_e	(1.001162 ± 0.000005) $e/2m_p$	$(2.210 \pm 0.002) \times 10^{-6}$	4.69×10^{17}	$e^- \bar{\nu}_e \nu_\mu$	100	14
	e^-	e^+	e^-	e^+	$\frac{1}{2}$	$-\frac{1}{2}$	$\frac{1}{2}$	$+$		0.510976 ± 0.000007	$1 m_e$	$(1.0011609 \pm 0.0000024)$ $e/2m_e$	∞	∞			7, 15
	ν_μ^0	ν_μ^0	ν_μ^0	ν_μ^0	$\frac{1}{2}$	$-\frac{1}{2}$	$\frac{1}{2}$	$+$		< 2.5	$< 5 m_e$						16, 21
Photon	ν_e^0	ν_e^0	ν_e^0	ν_e^0	$\frac{1}{2}$	$-\frac{1}{2}$	$\frac{1}{2}$	$+$		< 0.00025	$< 5 \times 10^{-4} m_e$						17, 21
	γ^0	γ^0	γ^0	γ^0	1	0	0	$+$		0	0						21

如何对粒子分类

● 元素周期表



元素=质子+中子+电子

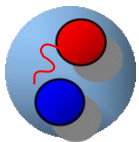
门捷列夫1871年元素周期表

Reihen	Gruppe I. — R ⁰	Gruppe II. — R ⁰	Gruppe III. — R ⁰	Gruppe IV. RH ⁴ R ⁰	Gruppe V. RH ⁵ R ⁰	Gruppe VI. RH ⁶ R ⁰	Gruppe VII. RH ⁷ R ⁰	Gruppe VIII. — R ⁰
1	H=1							
2	Li=7	Be=9,4	B=11	C=12	N=14	O=16	F=19	
3	Na=23	Mg=24	Al=27,3	Si=28	P=31	S=32	Cl=35,5	
4	K=39	Ca=40	—=44	Ti=48	V=51	Cr=52	Mn=55	Fe=56, Co=59, Ni=59, Cu=63.
5	(Ca=63)	Zn=65	—=68	—=72	As=75	Se=73	Br=80	
6	Rb=85	Sr=87	?Yt=88	Zr=90	Nb=94	Mo=96	—=100	Ru=104, Rh=104, Pd=106, Ag=108.
7	(Ag=108)	Cd=112	In=113	Sn=118	Sb=122	Te=125	J=127	
8	Cs=133	Ba=137	?Di=138	?Ce=140	—	—	—	—
9	(—)	—	—	—	—	—	—	—
10	—	—	?Er=178	?La=180	Ta=182	W=184	—	Os=195, Ir=197, Pt=198, Au=199.
11	(Au=199)	Hg=200	Tl=204	Pb=207	Bi=208	—	—	—
12	—	—	—	Th=231	—	U=240	—	—

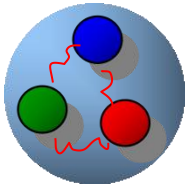
● 八重法 (The Eightfold Way)



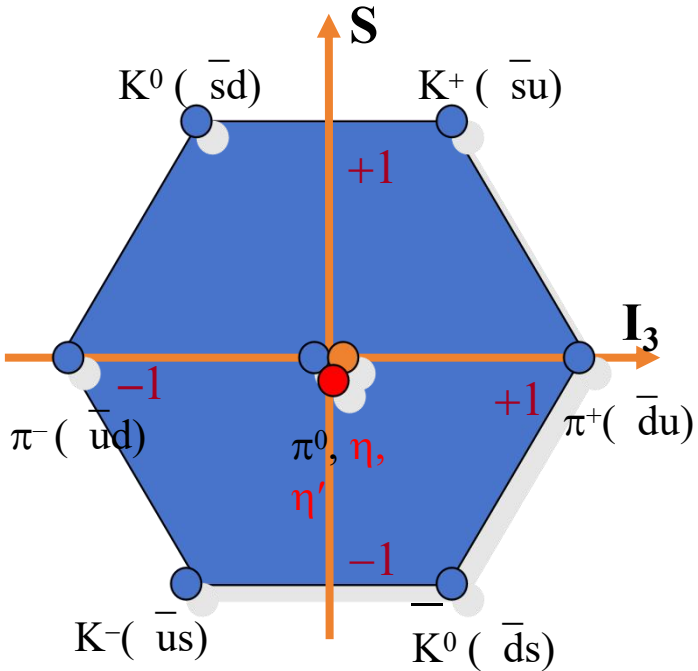
量子数\夸克	down	up	strange
电荷	-1/3	+2/3	-1/3
同位旋	1/2	1/2	0
同位旋z分量	-1/2	+1/2	0
奇异数	0	0	-1



介子($q\bar{q}$)

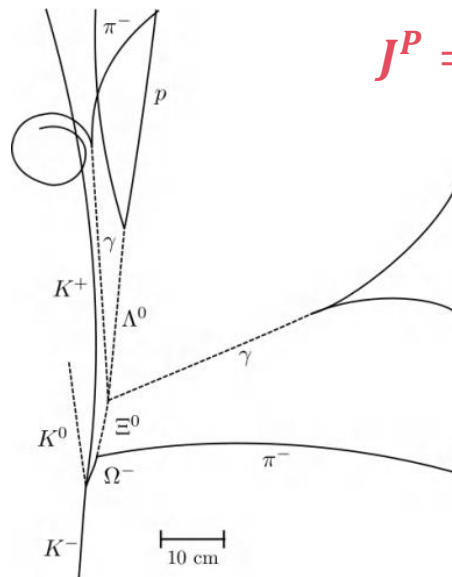
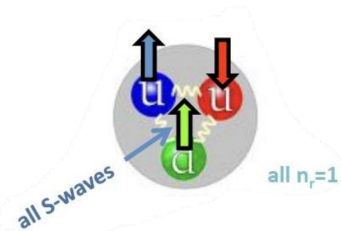
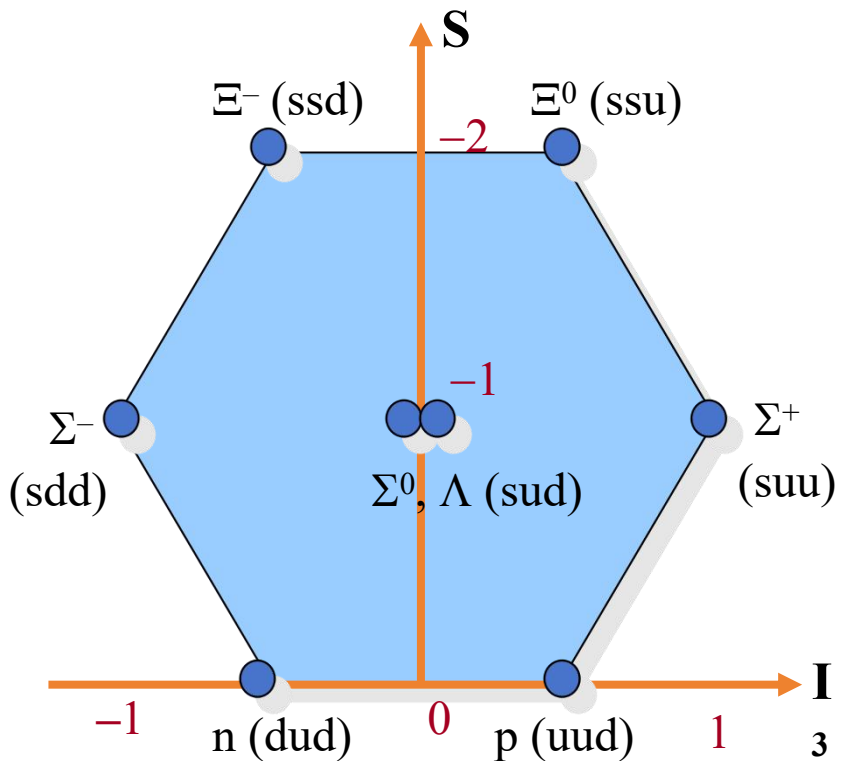


重子(qqq)

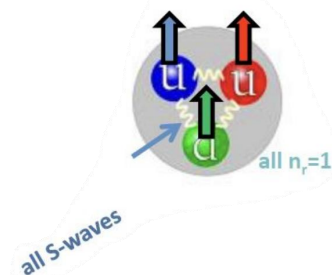
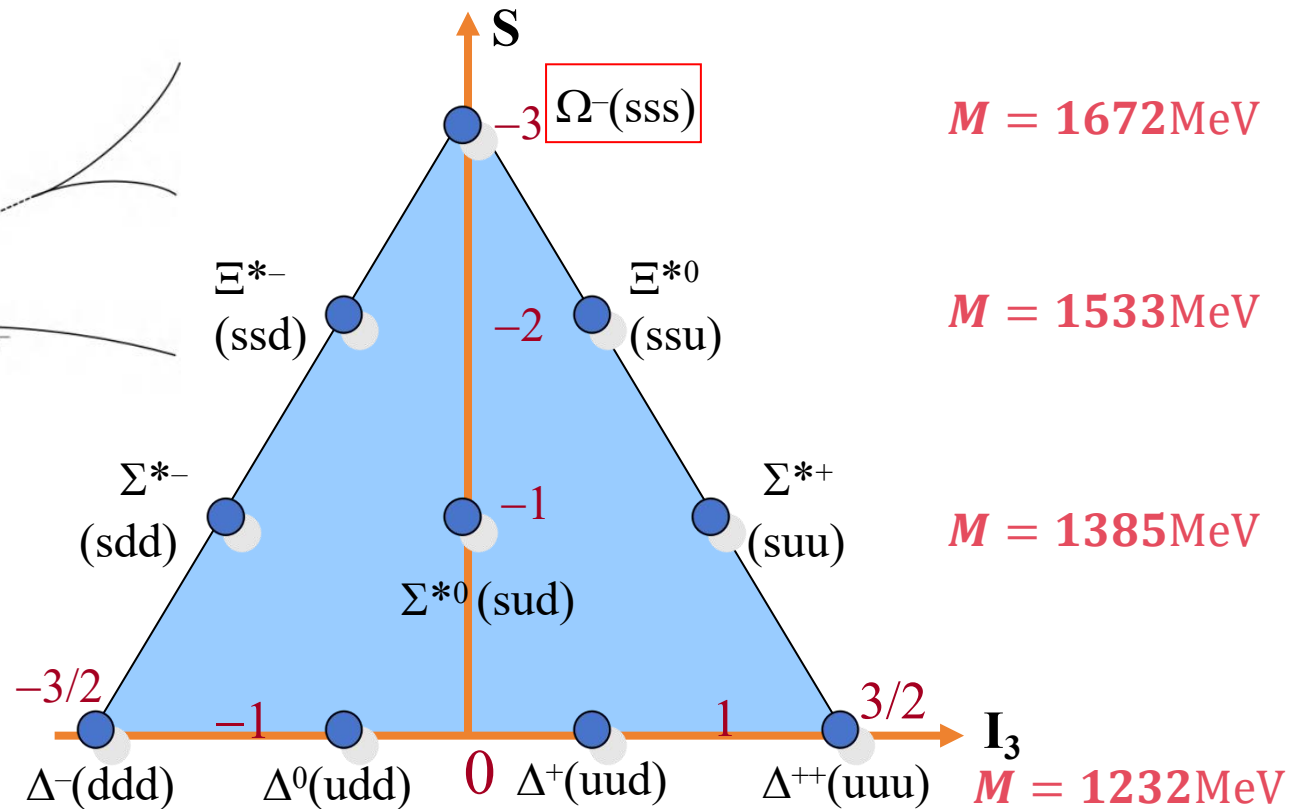


夸克模型的成功预言SU(3)多重态

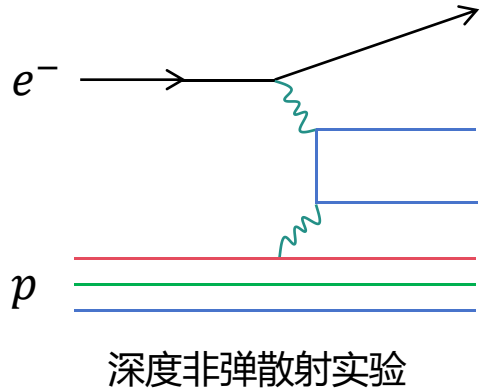
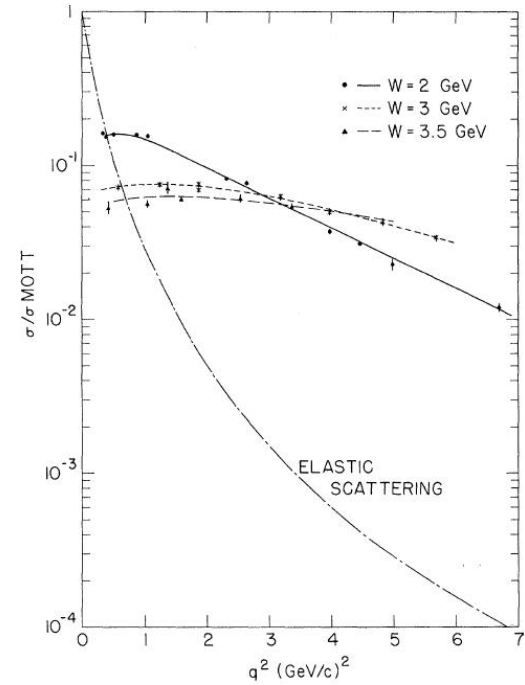
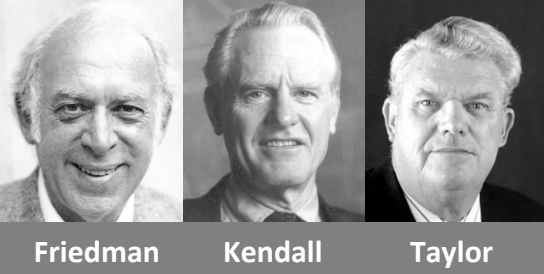
$J^P = 1/2^+$



$J^P = 3/2^+$



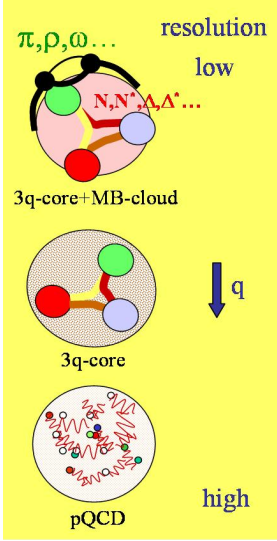
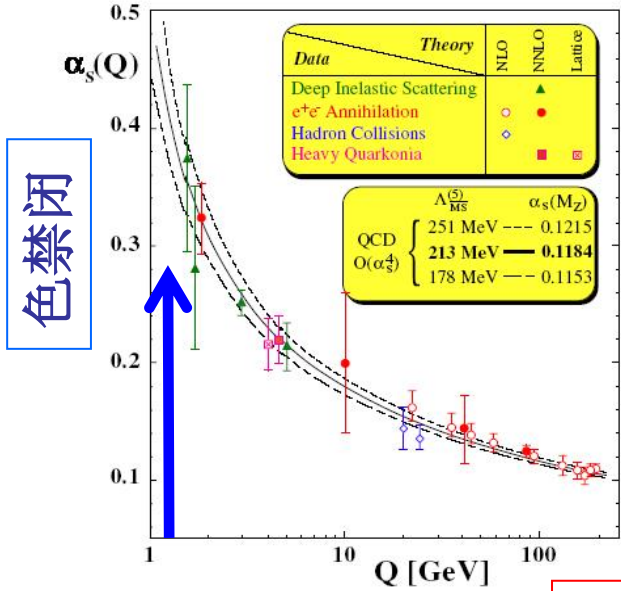
● 核子由夸克组成的实验验证



● 量子色动力学QCD理论

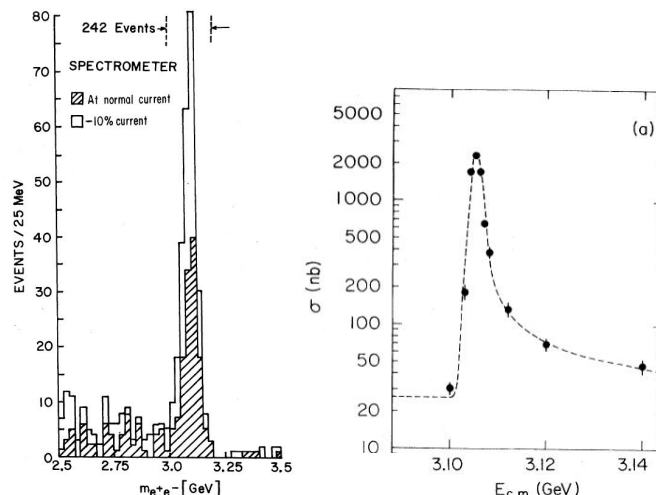


SU(3)非阿贝尔规范理论

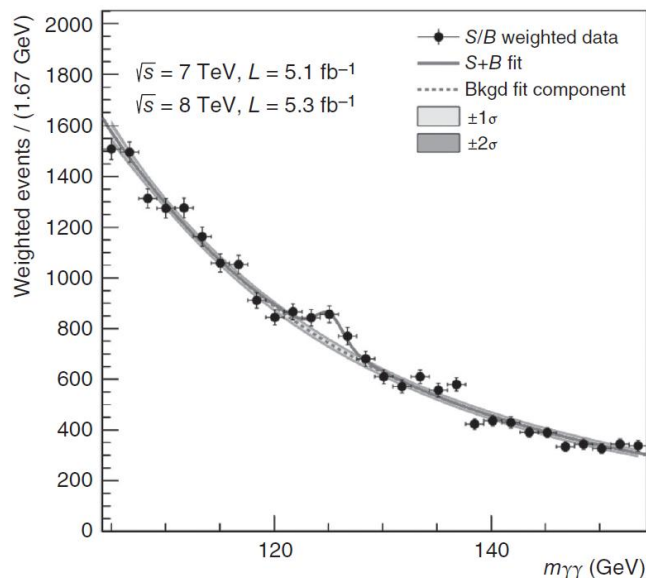


标准模型的补全

● 第四种夸克(粲夸克)



● 希格斯玻色子



粒子物理标准模型

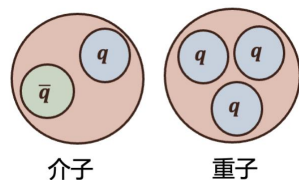
三代物质粒子 (费米子)

质量 电荷 自旋	I	II	III			
	$=2.2 \text{ MeV}/c^2$ $2/3$ $1/2$  上	$=1.28 \text{ GeV}/c^2$ $2/3$ $1/2$  粲	$=173.1 \text{ GeV}/c^2$ $2/3$ $1/2$  顶	0 0 1  胶子	$=125.09 \text{ GeV}/c^2$ 0 0  希格斯玻色子	标量玻色子
	$=4.7 \text{ MeV}/c^2$ $-1/3$ $1/2$  下	$=96 \text{ MeV}/c^2$ $-1/3$ $1/2$  奇	$=4.18 \text{ GeV}/c^2$ $-1/3$ $1/2$  底	0 0 1  光子		
	$=0.511 \text{ MeV}/c^2$ -1 $1/2$  电子	$=105.66 \text{ MeV}/c^2$ -1 $1/2$  μ 子	$=1.7768 \text{ GeV}/c^2$ -1 $1/2$  τ 子	$=91.19 \text{ GeV}/c^2$ 0 1  Z玻色子	规范玻色子	
$<2.2 \text{ eV}/c^2$ 0 $1/2$  ν_e 电中微子	$<1.7 \text{ MeV}/c^2$ 0 $1/2$  ν_μ μ 中微子	$<15.5 \text{ MeV}/c^2$ 0 $1/2$  ν_τ τ 中微子	$=80.39 \text{ GeV}/c^2$ ± 1 1  W玻色子			
轻子						

● 强子

mass →	≈2.3 MeV/c ²	≈1.275 GeV/c ²	≈173.07 GeV/c ²	0
charge →	2/3	2/3	2/3	0
spin →	1/2	1/2	1/2	1
	u	c	t	g
	up	charm	top	gluon

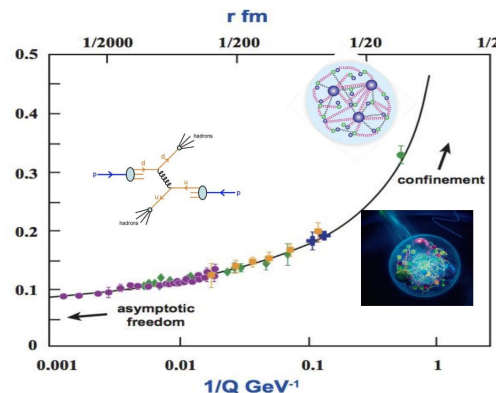
QUARKS	≈4.8 MeV/c ²	≈95 MeV/c ²	≈4.18 GeV/c ²
	-1/3	-1/3	-1/3
	1/2	1/2	1/2
	d	s	b
	down	strange	bottom



组分+构型+QCD=强子

● 实际困难

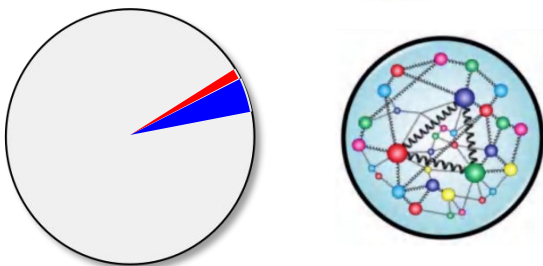
QCD在低能区域的非微扰特性



质子的质量来源:

Higgs机制: ~ 1%

强相互作用: ~ 95%



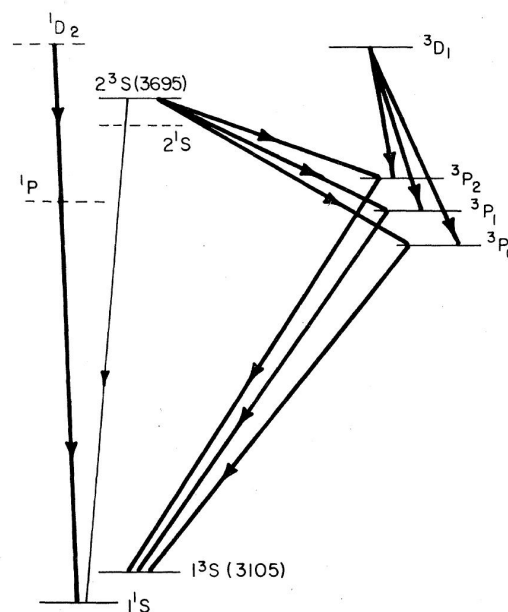
● 唯象模型

组分夸克模型、QCD求和规则、格点QCD、有效场论、色散理论等等

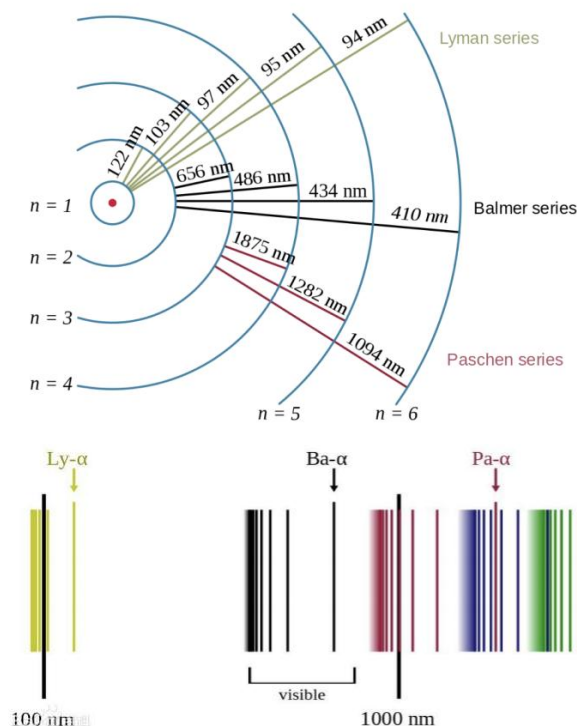
对于 $c\bar{c}$ 体系使用组分夸克模型

$$\text{康奈尔势: } V_0(r) = \sigma r - \frac{4/3\alpha_s}{r} + C_0$$

$$\text{哈密顿量: } \hat{H}_0 = \frac{p^2}{m_Q} + V_0(r) + V_{SD}(r)$$



● 氢原子光谱学

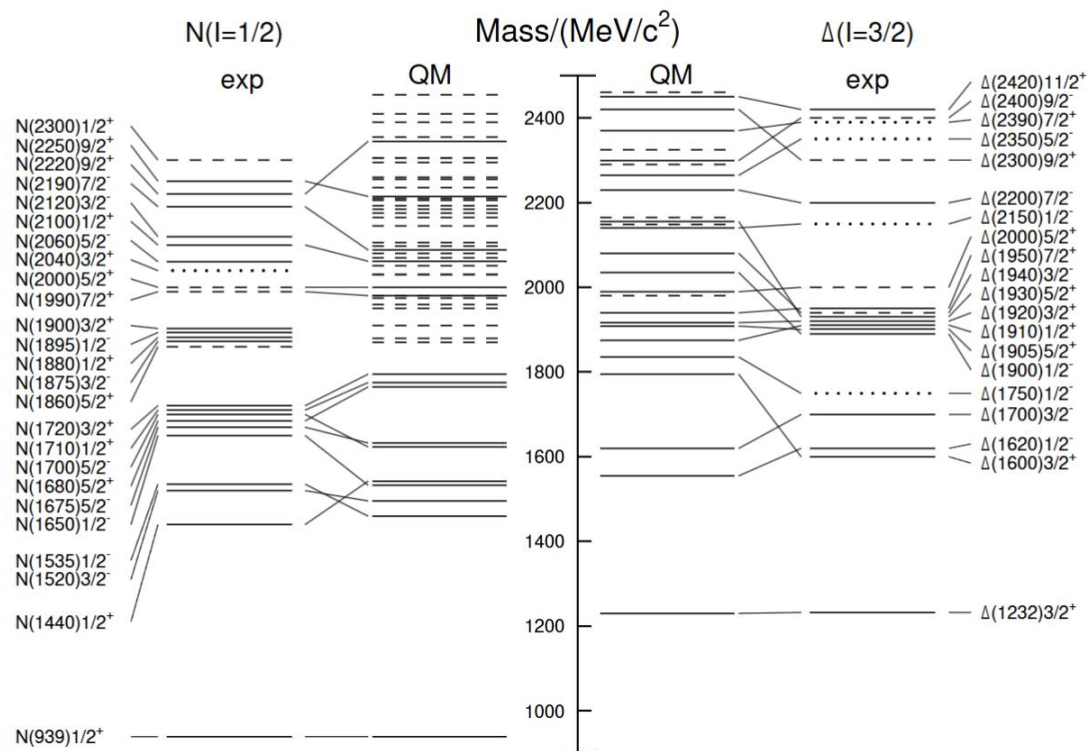


对光谱精细结构的不断研究反过来促进理论的不
断修改与认识:

粗结构(薛定谔方程)→精细结构(狄拉克方程)→兰姆位移(QED修正)→超精细结构(核自旋与电子角动量耦合)

● 强子谱学

复合体系受外部能量激发跃迁到更高的能量态,对这些态按照量子数、质量、组分等固有属性进行体系化的梳理与分类

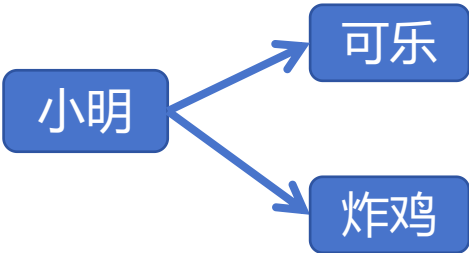
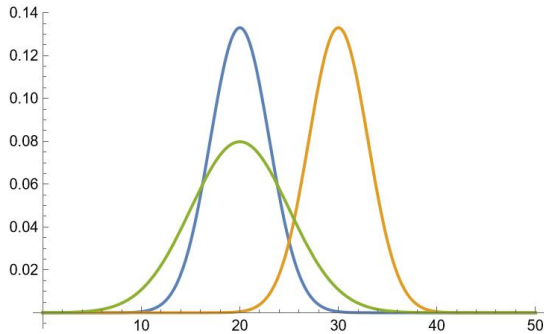


- 末态粒子重构

共振态粒子不稳定会衰变到稳定粒子

- 用统计小明零花钱的例子说明

	第1天	第2天	第3天	第4天	第5天	...
可乐(2元)	2	0	0	1	2	...
哇哈哈(1元)	1	0	5	3	1	...
炸鸡(10元)	0	0	0	1	1	...
薯条(5元)	0	1	0	1	1	...
汉堡(15元)	1	1	1	0	0	...
总钱数	20	20	20	20	20	...



- 对应到共振态参数

被调查人名字	粒子名称
零花钱数	质量
零花钱概率分布	衰变宽度
不同零食组合	衰变道
零食偏爱程度	耦合强度
多层级派发零花钱	级联衰变

可以在共振态更偏爱的反应道中研究其性质!

用于实验测量的反应过程

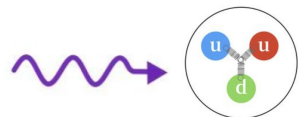
- 正负电子对撞



- 电生过程



- 光生过程

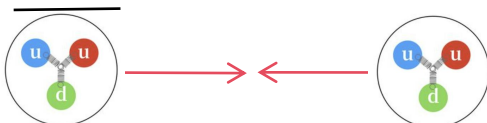


CLAS Collaboration

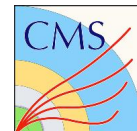
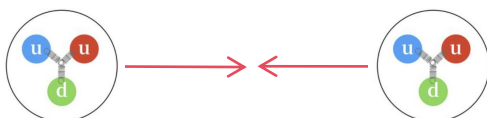
- 介子诱导过程



- 正反质子对撞



- 质子质子对撞

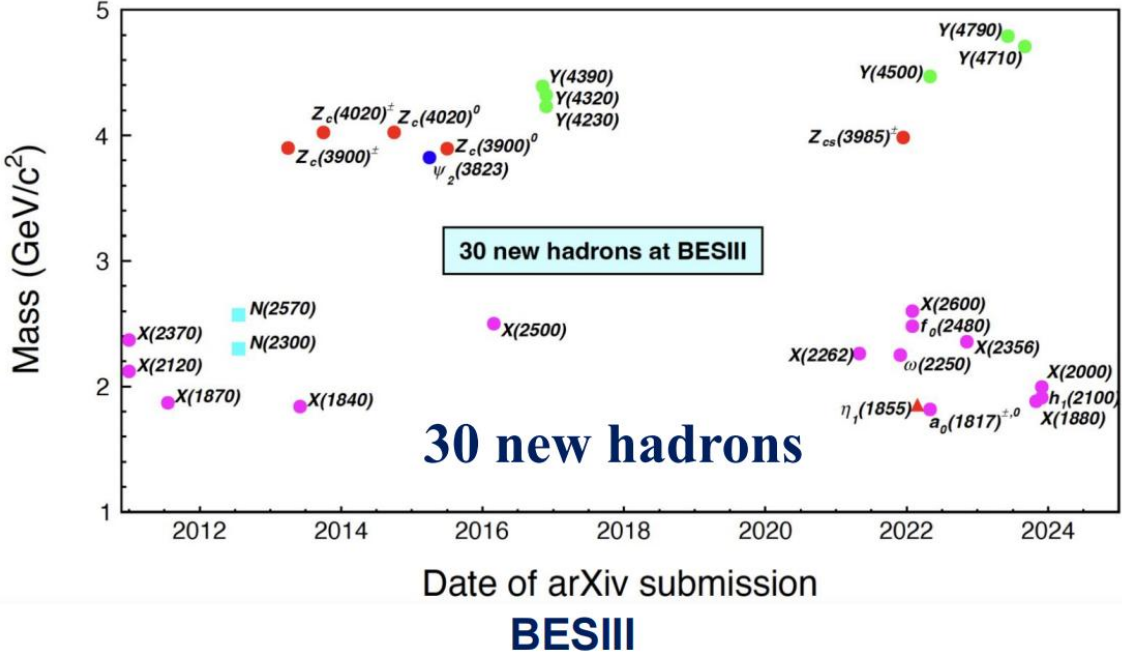
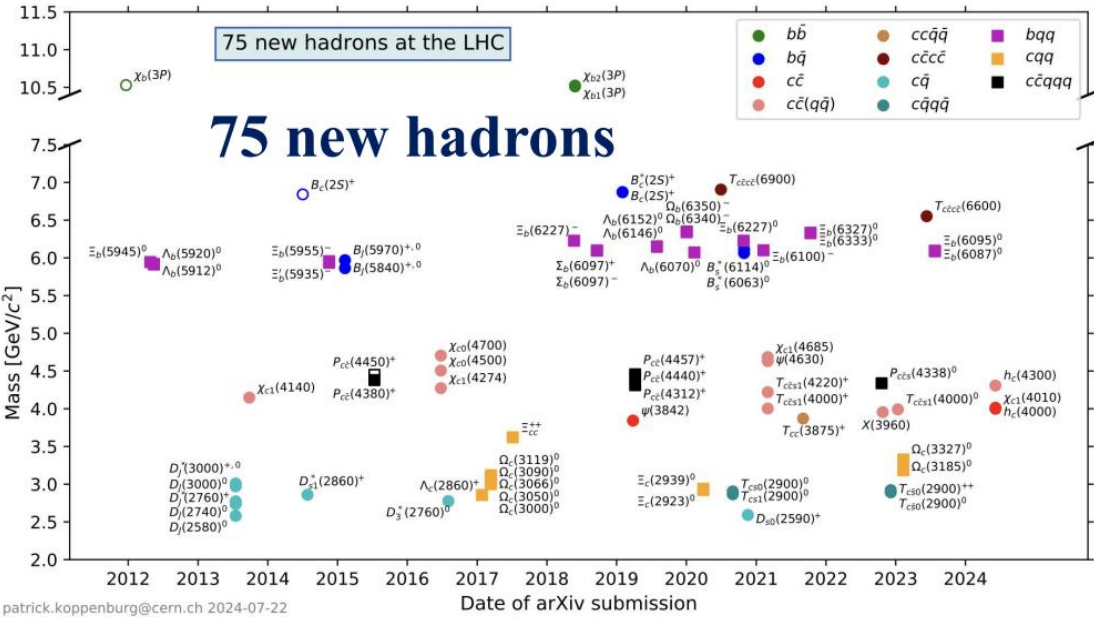


- 重离子对撞



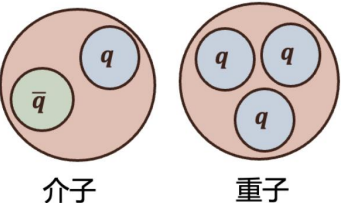
- 中微子实验

江门中微子实验室



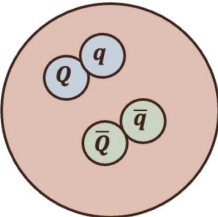
LHC (mainly LHCb)

● 传统强子态构型

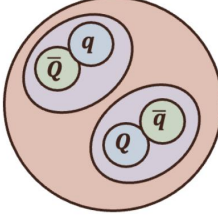


● 奇特强子态构型

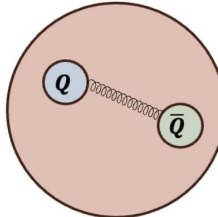
紧致四夸克态



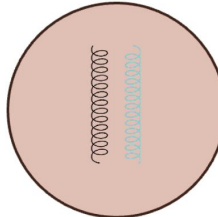
强子分子态



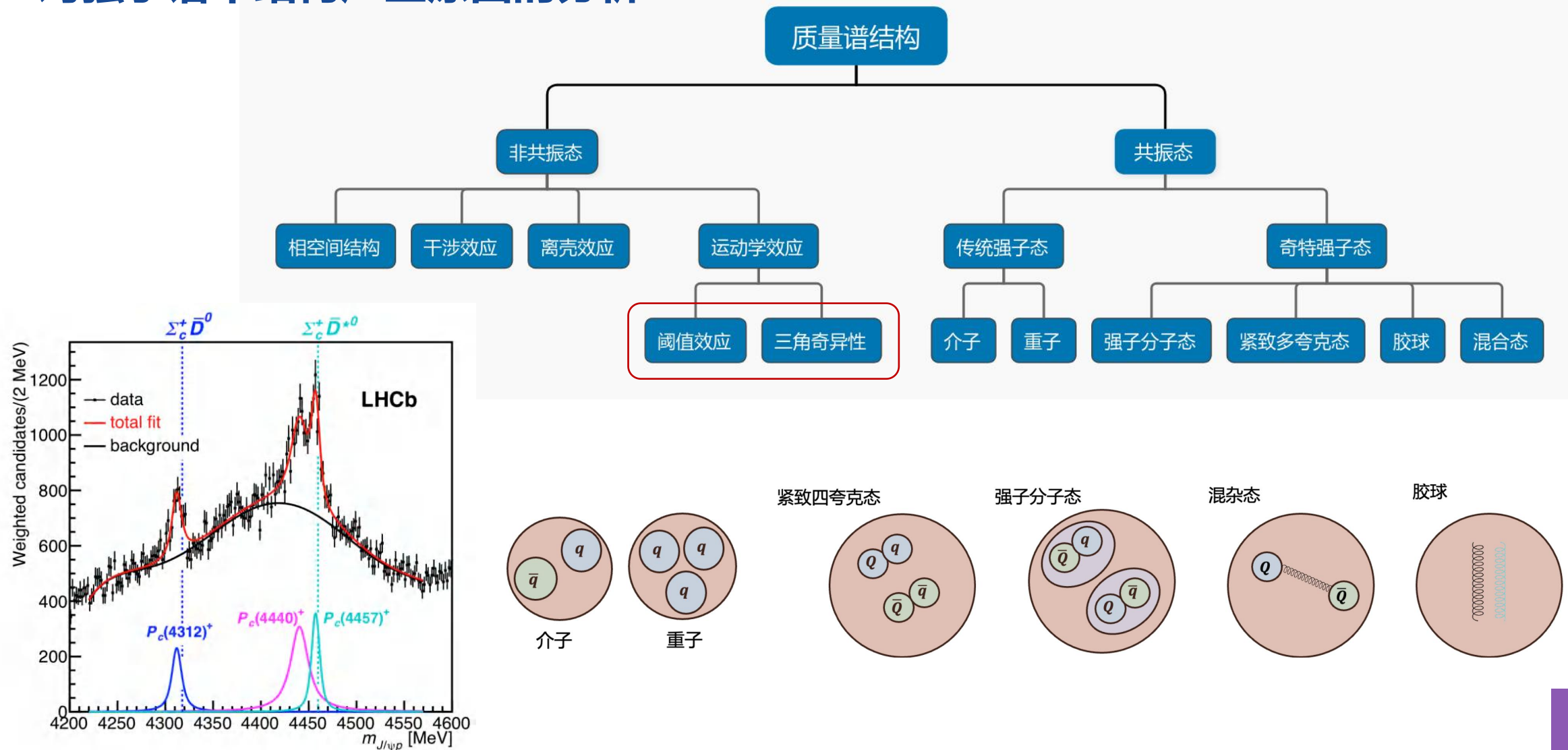
混杂态



胶球

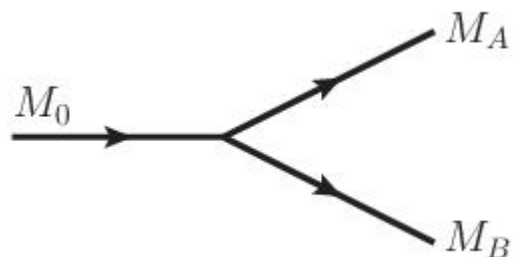


● 对强子谱中结构产生原因的分析

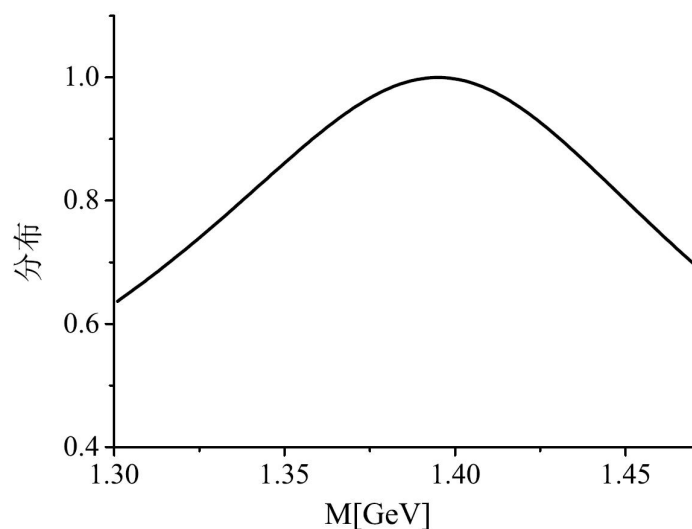


共振态产生与三角奇异性在不变质量谱中的结构

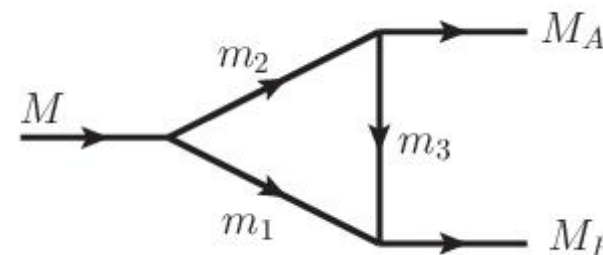
● 共振态产生



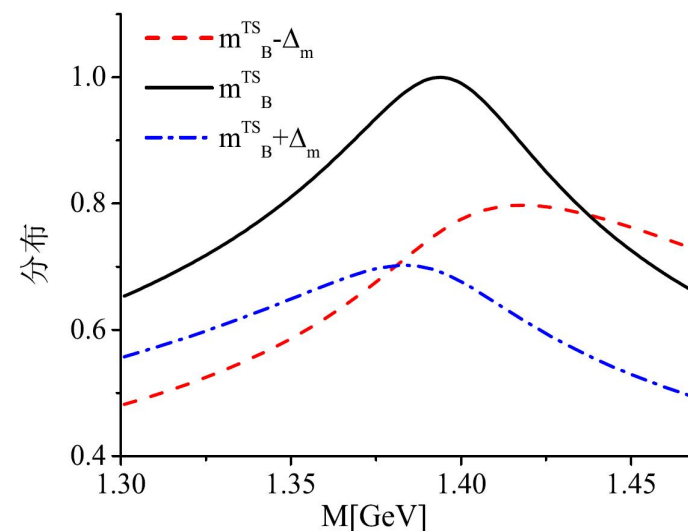
Breit-Wigner分布:
$$\frac{1}{M^2 - M_0^2 + iM_0\Gamma_0}$$



● 运动学奇点



$$\int \frac{dq^4}{(q^2 - m_1^2)(p_2^2 - m_2^2 + im_2\Gamma_2)(p_3^2 - m_3^2)}$$



- **Laudau 方程 (Nucl. Phys. 13, 181 (1959))**

阈值奇点(threshold cusp), 三角奇点(triangle singularity),...

- **近年对三角奇点 (TS) 的研究现状**

(see Prog. Part. Nucl. Phys. 112 (2020) 103750 for a review)

J.J. Wu, X.-H. Liu, Q. Zhao, B.-S. Zou, PRL108, 081003 (2012);

Q. Wang, C. Hanhart, Q. Zhao, PRL111, 132003 (2013); PLB725, 106 (2013)

X.-H. Liu, M. Oka and Q. Zhao, PLB753, 297(2016);

Q. Huang, C. W. Shen and J. J. Wu, PRD103,016014(2021)

... ..

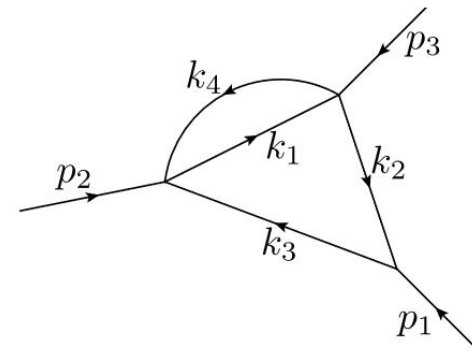
- **对振幅中三角奇异性研究的重要意义**

解释不变质量谱中某些结构的产生机制

解释某些反应过程为什么存在巨大的同位旋破缺效应

解释某些强子态的性质

... ..

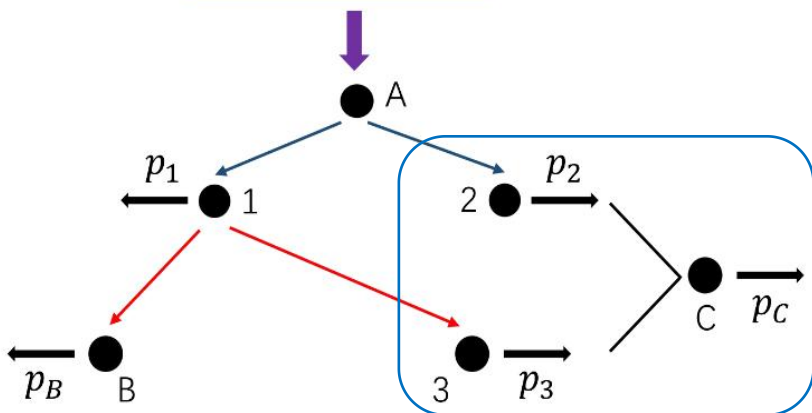
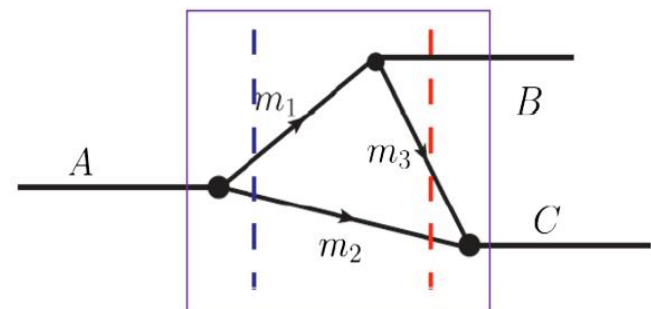


产生的运动学条件:

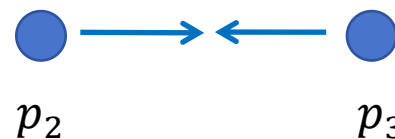
- 内线三个粒子同时在壳
- 在A粒子质心系中, $\vec{p}_2 \parallel \vec{p}_3$, 并且粒子3可以追上粒子2

所具备的性质:

- 产生位置在强子对阈值附近
- 产生位置依赖于运动学参数
- 会在不变质量谱中产生尖锐的结构
- 会对末态粒子的自旋观测量产生影响



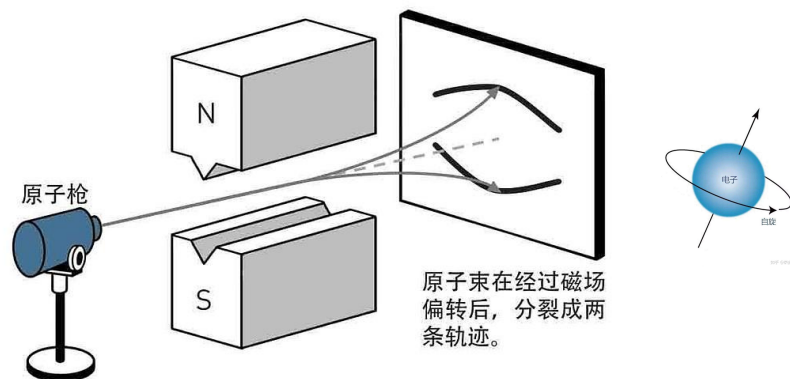
Q.Huang, C.W.Shen, J.J.Wu, PRD103(2021)016014



隐藏的对撞过程!

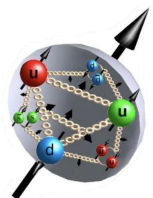
运动学条件对自旋观测量的影响

● 电子自旋



斯特恩盖拉赫实验观测到电子自旋现象

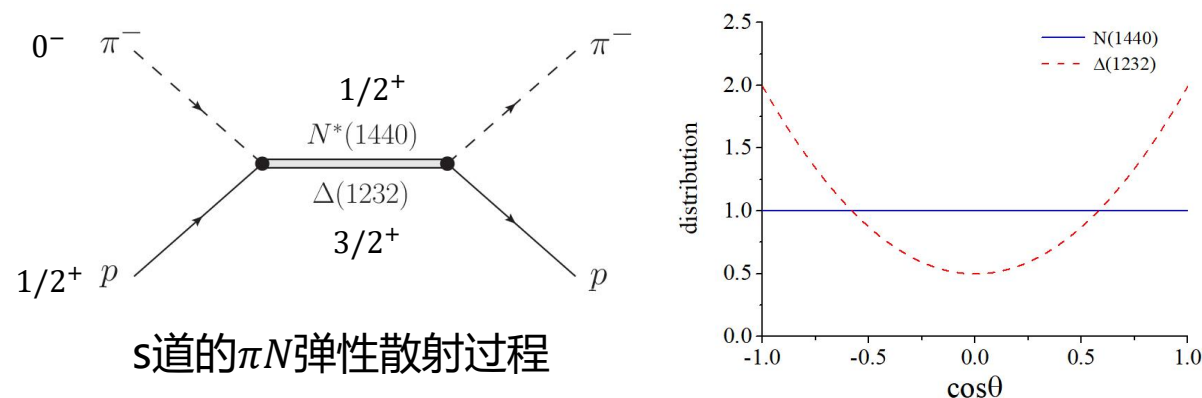
● 强子自旋



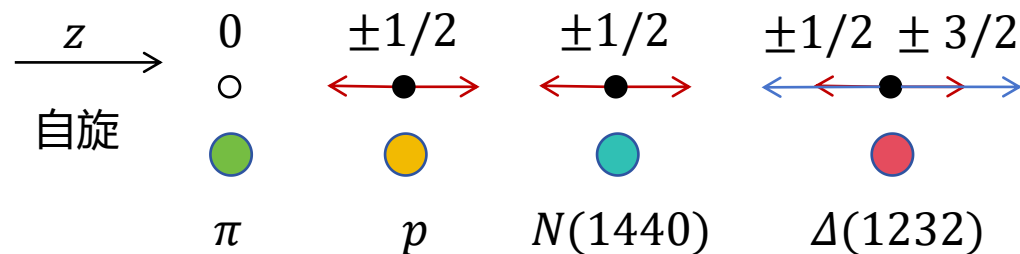
介子(玻色子): 整数自旋 0, 1, 2...

重子(费米子): 半整数自旋 1/2, 3/2, 5/2...

● 对撞过程中的自旋排列效应



总角动量第三分量守恒

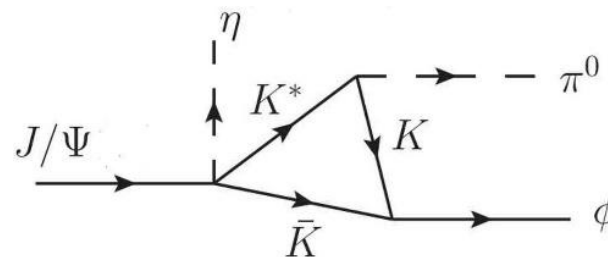


$$\begin{array}{c} \text{角动量} \\ \text{三分量} \end{array} \quad \begin{array}{c} \pm 1/2 \\ \leftarrow \bullet \rightarrow \end{array} + \begin{array}{c} 0 \\ \circ \end{array} = \begin{array}{c} \pm 1/2 \\ \leftarrow \bullet \rightarrow \end{array}$$

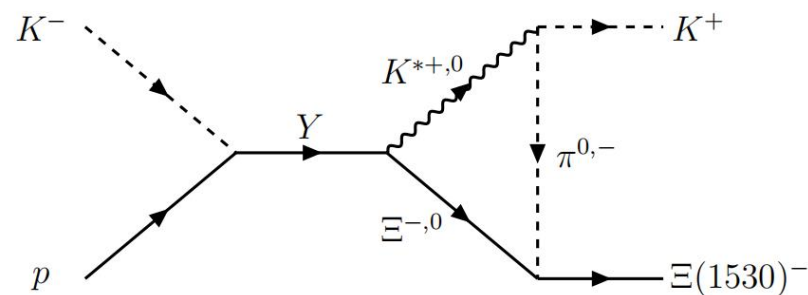
总自旋 轨道 总角动量

用自旋观测量研究强子谱中的近阈值结构

$J/\psi \rightarrow \eta \pi^0 \phi$ 反应末态 $\pi^0 \phi$ 不变质量谱中的结构

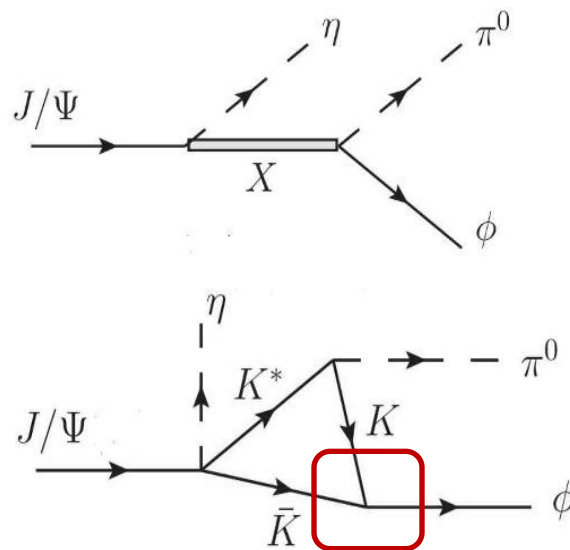
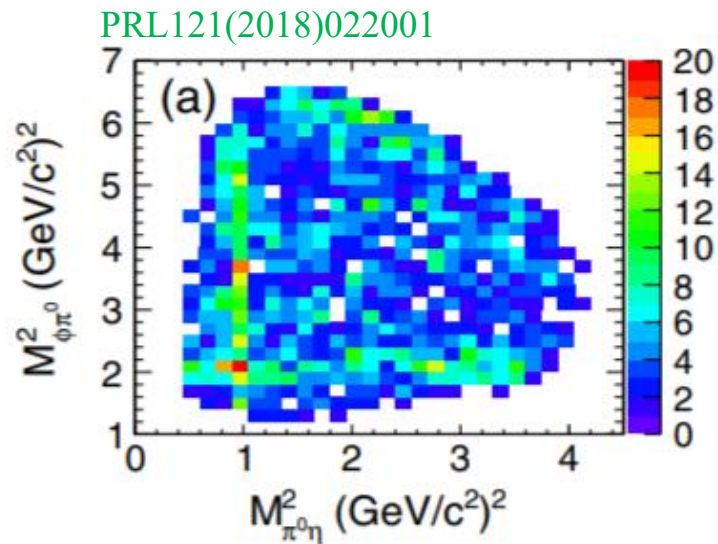


$K^- p \rightarrow K^+ \Xi(1530)^-$ 反应总截面中的结构



$J/\psi \rightarrow \phi \eta \pi^0$ 反应

● 在 $M_{\phi\pi^0} = 1.4 \text{ GeV}$ 附近结构的产生原因



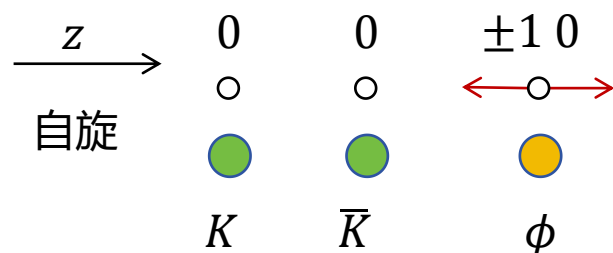
共振态

?

运动学效应中的三角奇异性

PRD100(2019)114010

● 自旋观测量分析



$$\begin{array}{ccc} \text{角动量} & 0 & 0 \\ \text{三分量} & \circ & \circ \\ \text{总自旋} & + & \text{轨道} \\ & \circ & = \\ & \text{总角动量} & \end{array}$$

末态矢量 ϕ 介子在其动量方向的自旋分量只能为0!

● 共振态模型

$C(1480) \quad I(J^{PC}) = 1(1^{--})$ PLB188(1987)383

$h_1(1415) \quad I(J^{PC}) = 0(1^{+-})$ PDG

模型 I : $X = C(1480) \quad M_c = 1480\text{MeV} \quad \Gamma_c = 130\text{MeV}$

模型 II : $X = h_1(1415) \quad M_h = 1416\text{MeV} \quad \Gamma_h = 90\text{MeV}$

$$\begin{aligned} \mathcal{L}_{AVP} &= g_A(\mathcal{L}_a \cos \theta + \mathcal{L}_b \sin \theta), \\ \mathcal{L}_a &= A^\mu (\partial_\mu V_\nu - \partial_\nu V_\mu) \partial^\nu P, \\ \mathcal{L}_b &= \partial^\mu A^\nu (\partial_\mu V_\nu - \partial_\nu V_\mu) P, \end{aligned}$$

模型 IIA : $\theta_\pi = \pi/4$

模型 IIB : $\theta_\pi = 3\pi/4$

PRD76(2007)094030

● 三角奇异性模型

模型 III 对应图 (a)

$$\mathcal{M}_i = ig\epsilon_{J/\psi}^\mu \epsilon_\phi^{*\nu} \int \frac{d^4 q}{(2\pi)^4} \frac{[-g_{\mu\lambda} + (q+k_1)_\mu (q+k_1)_\lambda / m_{K^*}^2](q+2k_2-k_1)^\lambda (2q+k_2)^\nu}{(q^2 - m_{K_{id}}^2 + i\epsilon)[(q+k_1)^2 - m_{K^*}^2 + i\epsilon][(q+k_2)^2 - m_{K_{id}}^2 + i\epsilon]} \equiv ig\epsilon_{J/\psi}^\mu \epsilon_\phi^{*\nu} \mathcal{M}_{\mu\nu}^i,$$

PRD100(2019)114010

模型 IV 对应图 (b)

$$\mathcal{M}_i \equiv i \frac{g' \epsilon_{J/\psi, \rho} (-g^{\rho\mu} + k_1^\rho k_1^\mu / k_1^2) \epsilon_\phi^{*\nu} \mathcal{M}_{\mu\nu}^i}{k_1^2 - m_{h_1}^2 + im_{h_1} \Gamma_{h_1}},$$

总振幅

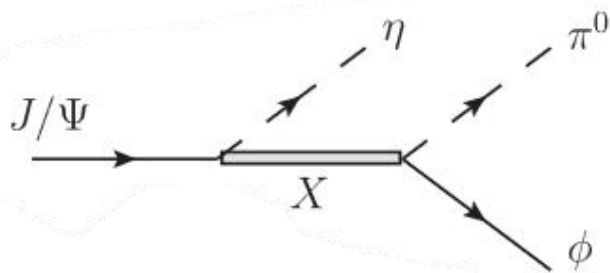
$$\mathcal{M} = 2(\mathcal{M}_C - \mathcal{M}_N).$$

自旋观测量的定义及共振态模型的结果

在 $\pi^0\phi$ 静止系中通过 ϕ 介子的螺旋度态定义自旋密度矩阵元 ρ_{00}^ϕ

$$\rho_{00}^\phi(m_{\pi^0\phi}) = \frac{\int d\Omega_\eta d\Omega_{\pi^0} \sum_m \mathcal{M}_{m,\lambda=0} \mathcal{M}_{m,\lambda'=0}^*}{\int d\Omega_\eta d\Omega_{\pi^0} \sum_{m,\lambda''} |\mathcal{M}_{m,\lambda''}|^2},$$

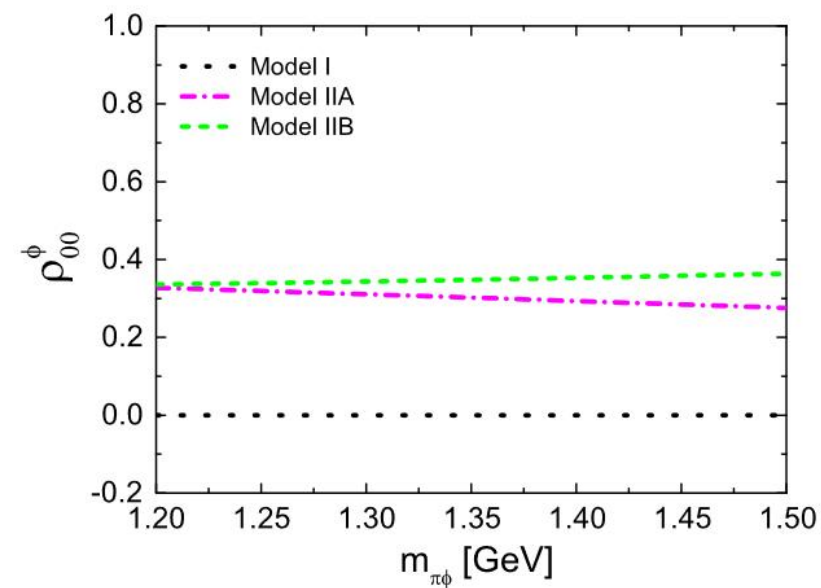
● 共振态模型结果



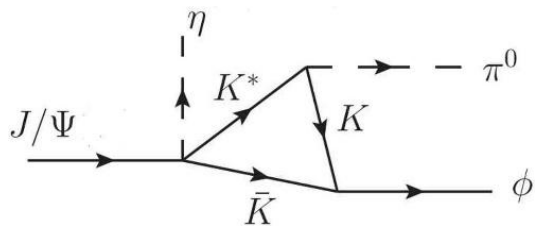
模型 I: $X = C(1480) \quad I(J^{PC}) = 1(1^{--})$

模型 IIA: $X = h_1(1415) \quad \theta_\pi = \pi/4$

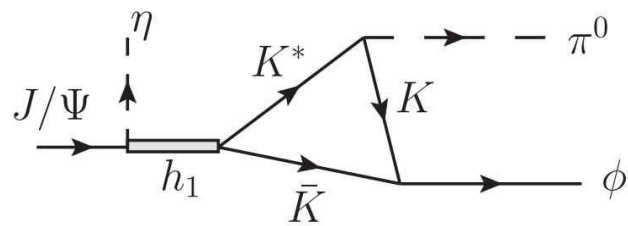
模型 IIB: $X = h_1(1415) \quad \theta_\pi = 3\pi/4$



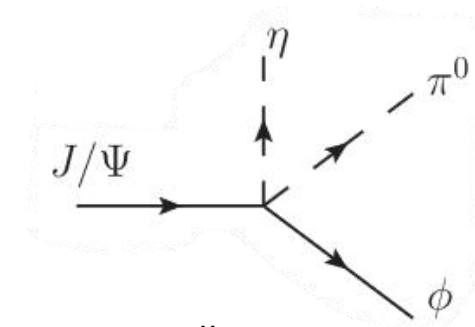
三角奇异性模型结果



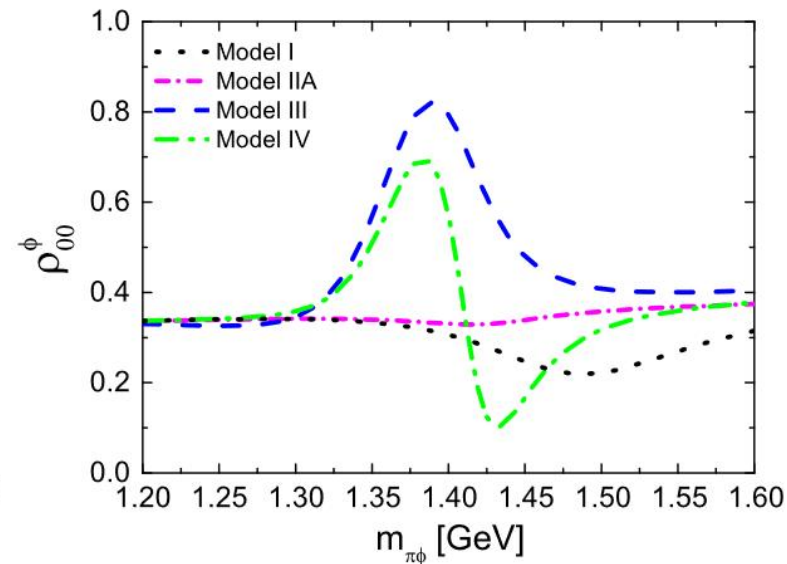
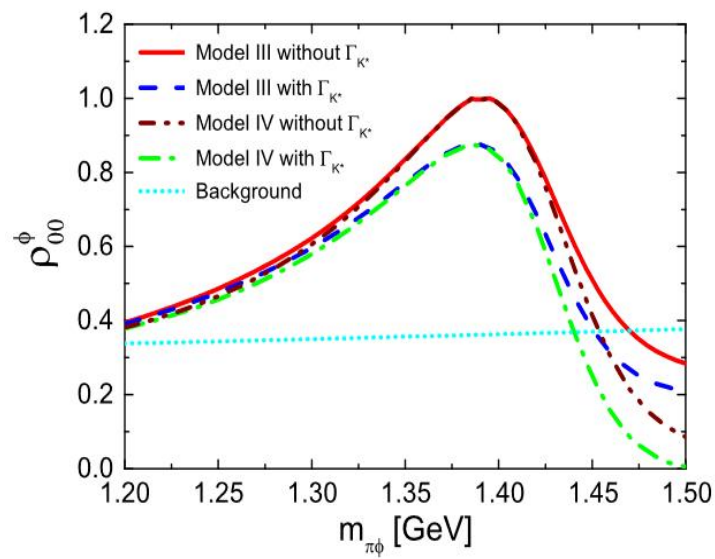
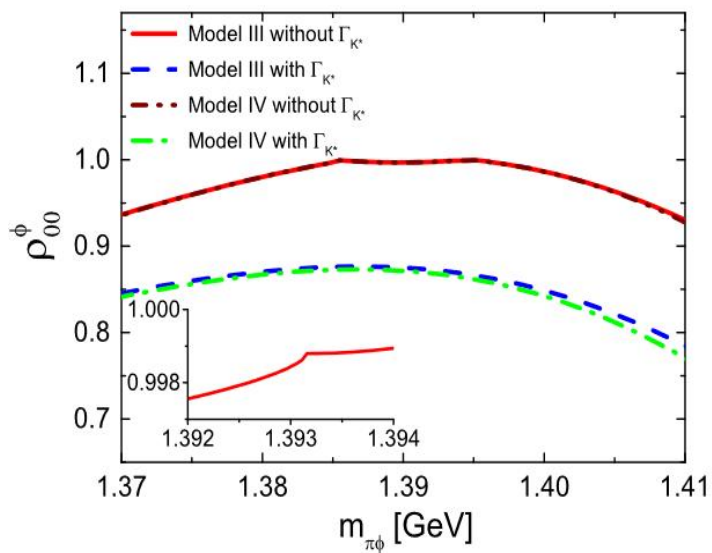
模型 III



模型 IV

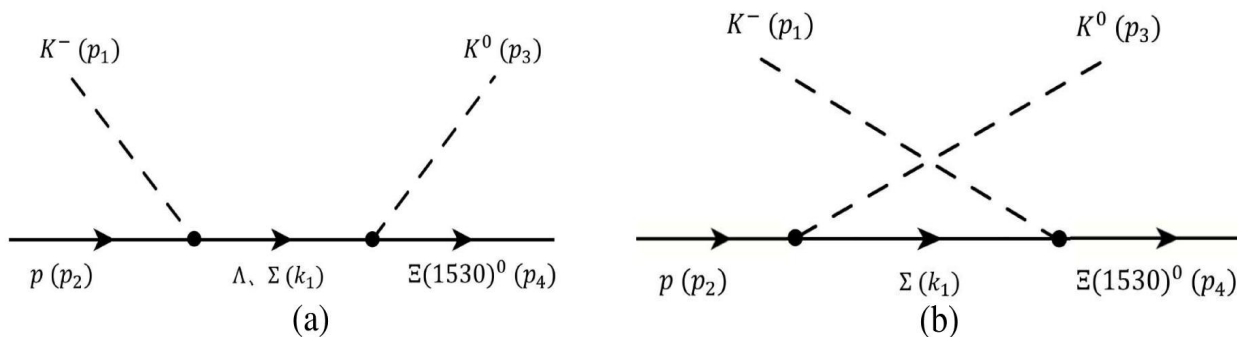


背景项

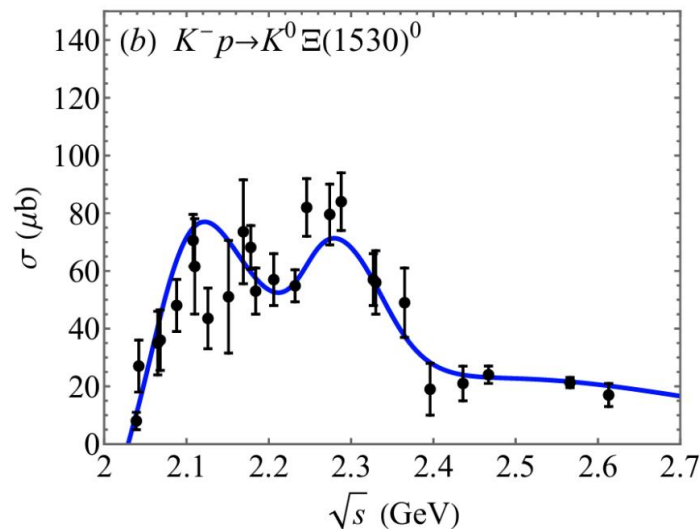
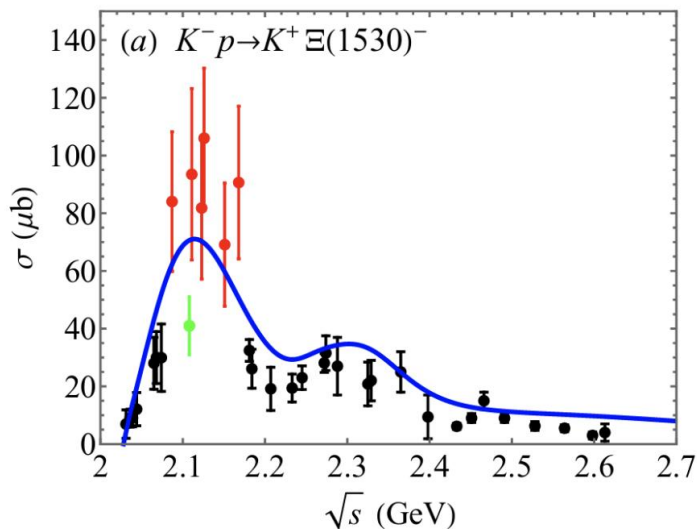


$K^- p \rightarrow K^+ \Xi(1530)^-$ 反应

D. Y. Chen, arXiv:2507.02232



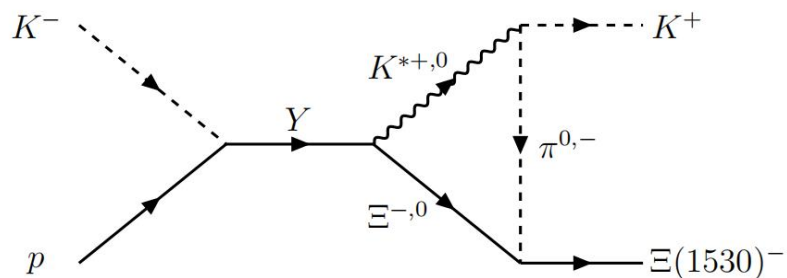
费曼图



总截面

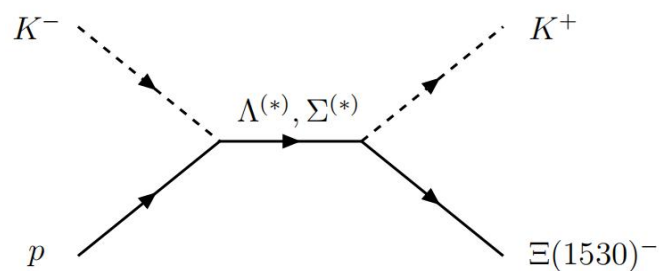
TABLE I: The resonance parameters of the involved Λ and Σ hyperon and their resonances.

State	J^P	Mass (MeV)	Width (MeV)
$\Lambda(1116)$	$1/2^+$	1116	—
$\Lambda(1405)$	$1/2^-$	1405	50
$\Lambda(1890)$	$3/2^+$	1890	120
$\Lambda(2110)$	$5/2^+$	2090	250
$\Lambda(2325)$	$3/2^-$	2325	170
$\Sigma(1193)$	$1/2^+$	1193	—
$\Sigma(1670)$	$3/2^-$	1662	55
$\Sigma(2080)$	$3/2^+$	2090	170
$\Sigma(2250)$	$5/2^-$	2250	100

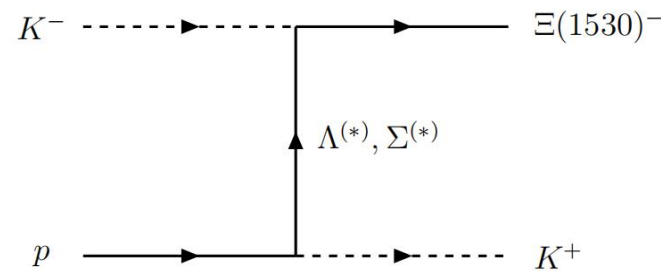


三角圈图费曼图

$$M_{K\Xi^*}^{TS} = 2.25 \text{ GeV}$$



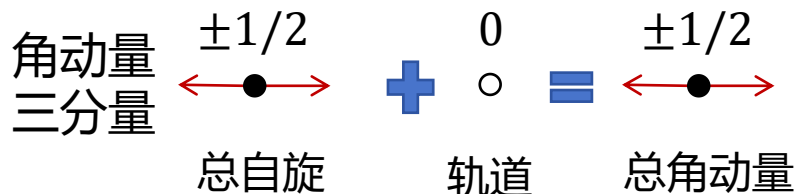
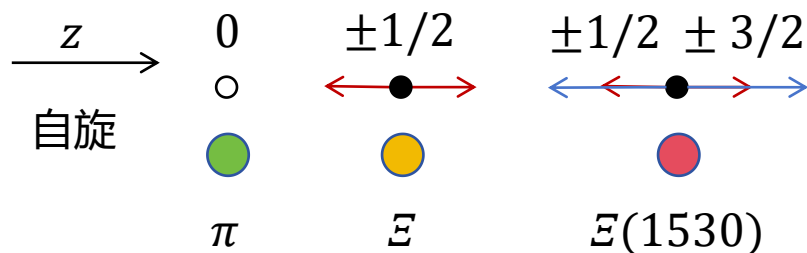
(a)



(b)

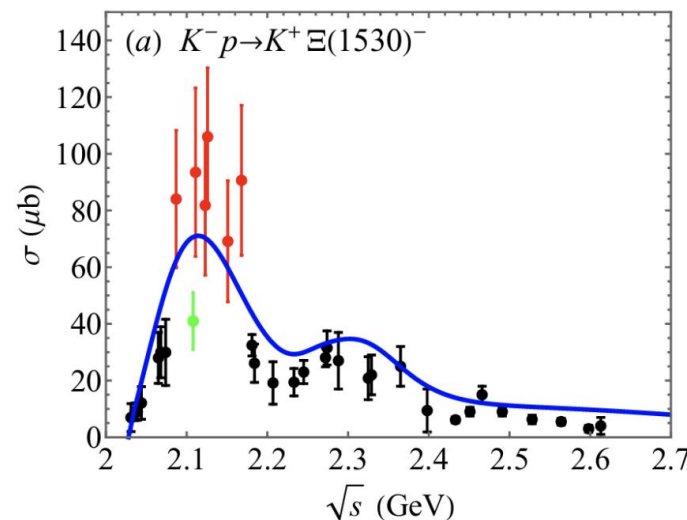
树图费曼图

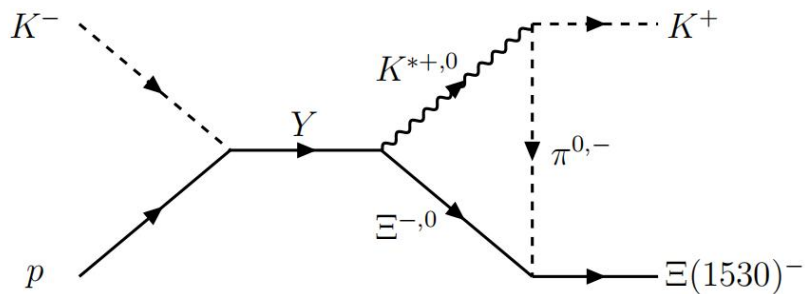
● 自旋观测量分析



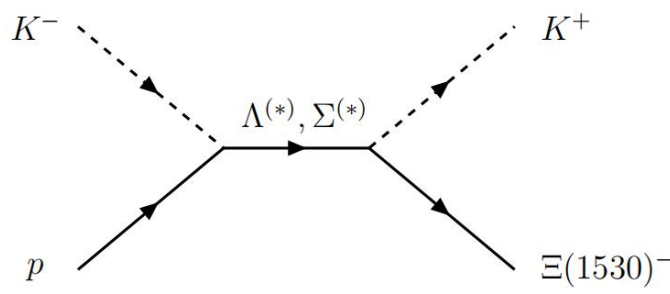
研究目标:

- 讨论三角奇异性对总截面中2.25GeV附近结构的影响
- 预言 $\Xi(1530)$ 粒子的自旋观测量
- 讨论用自旋观测量区分共振态模型和三角奇异性模型的可能

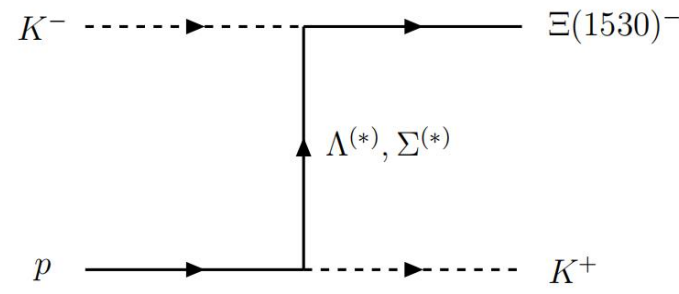




三角圈图费曼图



(a)



(b)

树图费曼图

● 总振幅

● 共振态模型

$$\begin{aligned} \mathcal{M}_I^{\text{Total}} = & \mathcal{M}_{\Lambda(1116)}^s + \mathcal{M}_{\Lambda(2050)}^s + \mathcal{M}_{\Lambda(2110)}^s + \mathcal{M}_{\Lambda(2325)}^s \\ & + \mathcal{M}_{\Sigma(1193)}^s + \mathcal{M}_{\Sigma(2250)}^s + \mathcal{M}_{\Lambda(1116)}^u \\ & + \mathcal{M}_{\Lambda(2050)}^u + \mathcal{M}_{\Lambda(2325)}^u + \mathcal{M}_{\Sigma(1193)}^u \end{aligned}$$

● 三角奇异性模型

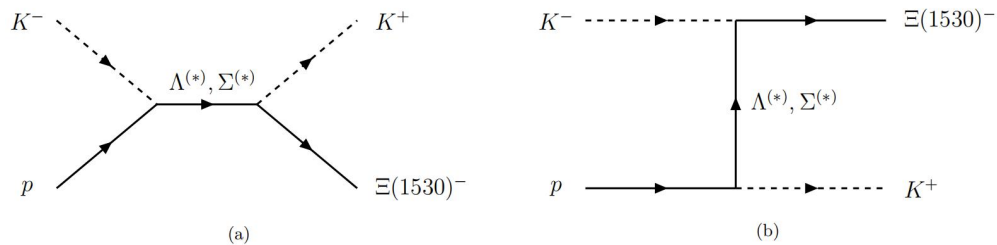
$$\begin{aligned} \mathcal{M}_{IIB,j}^{\text{Total}} = & e^{i\phi_j} \mathcal{M}^{\text{TS}} + \mathcal{M}_{\Lambda(1116)}^s + \mathcal{M}_{\Lambda(2050)}^s + \mathcal{M}_{\Sigma(1193)}^s \\ & + \mathcal{M}_{\Lambda(1116)}^u + \mathcal{M}_{\Lambda(2050)}^u + \mathcal{M}_{\Sigma(1193)}^u \end{aligned}$$

● 自旋观测量的定义

$$\rho_{\lambda\lambda'}(m_{\gamma\Delta}) = \frac{\int d\Omega_{\bar{p}} d\Omega_{\gamma}^* \sum_{\text{spin}}' \mathcal{M}_{\lambda}^T \mathcal{M}_{\lambda'}^{T*}}{\int d\Omega_{\bar{p}} d\Omega_{\gamma}^* \sum_{\text{spin}} |\mathcal{M}^T|^2}$$

$$P_{\Delta} = \frac{\rho_{11} - \rho_{33}}{\rho_{11} + \rho_{33}}$$

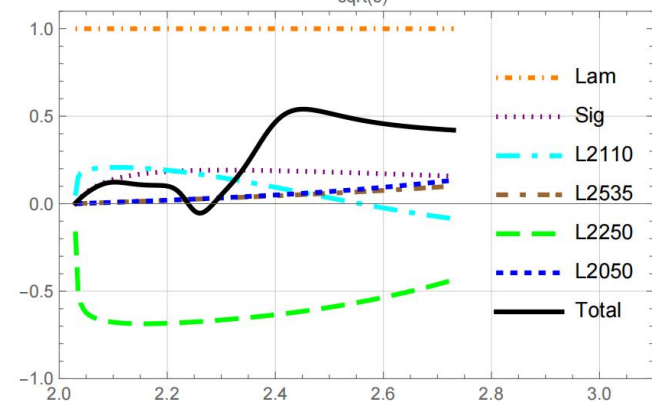
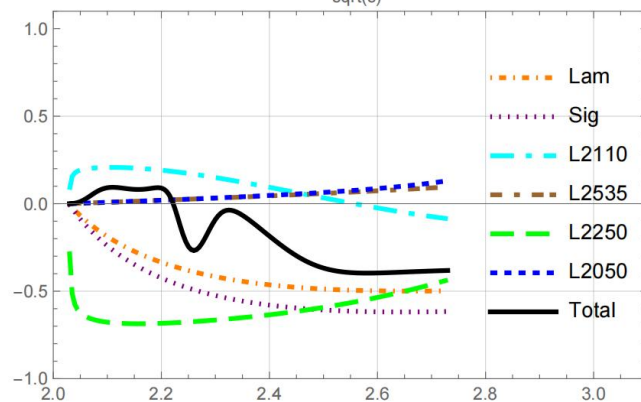
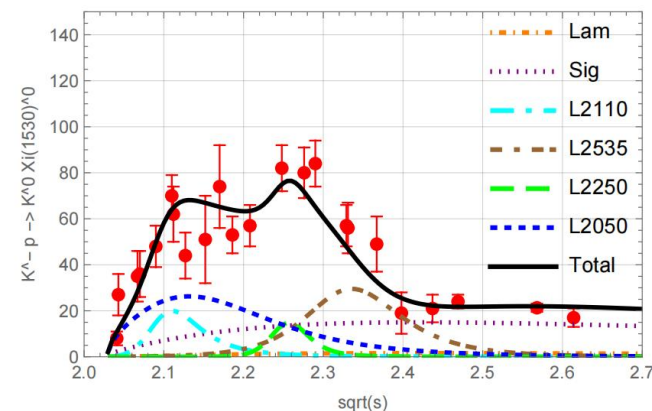
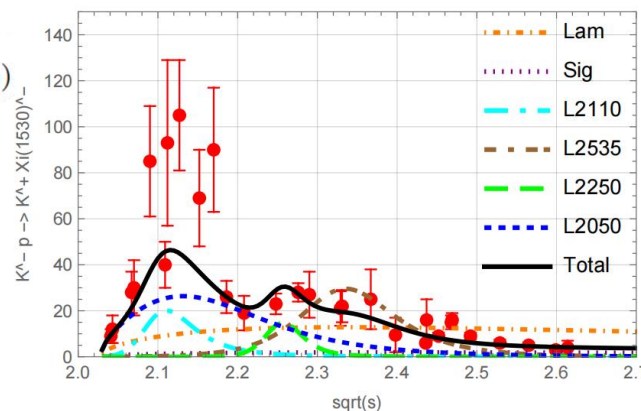
共振态模型结果



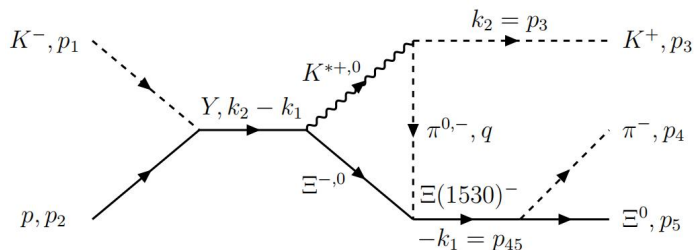
Coupling	Value	Coupling	Value
$g_{\Lambda(1116)}$	-1.738×10^{-1}	$g_{\Lambda(2325)}$	8.978×10^{-2}
$g_{\Lambda(2050)}$	-4.126×10^{-1}	$g_{\Sigma(1193)}$	3.743×10^{-1}
$g_{\Lambda(2110)}$	4.198×10^{-2}	$g_{\Sigma(2250)}$	1.837×10^{-2}
$\chi^2/d.o.f$	1.75		

$$\mathcal{M}_I^{\text{Total}} = \mathcal{M}_{\Lambda(1116)}^s + \mathcal{M}_{\Lambda(2050)}^s + \mathcal{M}_{\Lambda(2110)}^s + \mathcal{M}_{\Lambda(2325)}^s \\ + \mathcal{M}_{\Sigma(1193)}^s + \mathcal{M}_{\Sigma(2250)}^s + \mathcal{M}_{\Lambda(1116)}^u \\ + \mathcal{M}_{\Lambda(2050)}^u + \mathcal{M}_{\Lambda(2325)}^u + \mathcal{M}_{\Sigma(1193)}^u$$

States	J^P	Mass (MeV)	Width (MeV)
$\Lambda(1116)$	$1/2^+$	1116	-
$\Lambda(2050)$	$3/2^-$	2056	490
$\Lambda(2110)$	$5/2^+$	2090	250
$\Lambda(2325)$	$3/2^-$	2325	177
$\Sigma(1193)$	$1/2^+$	1193	-
$\Sigma(2250)$	$5/2^-$	2250	100

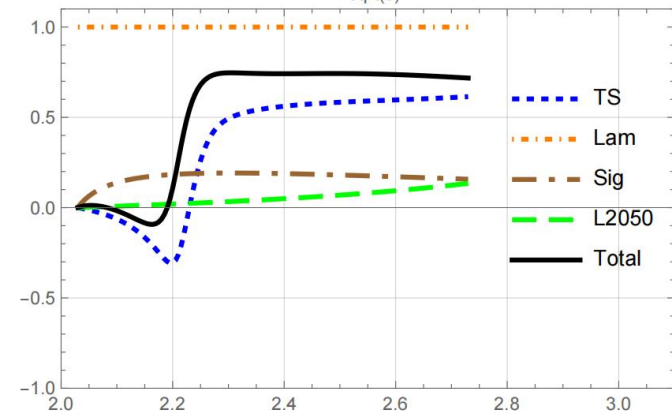
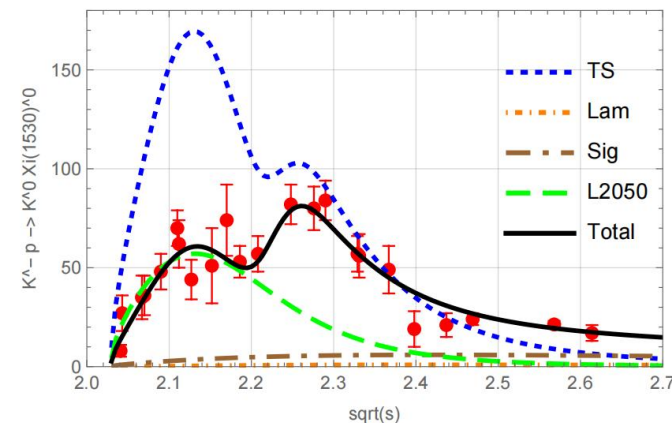
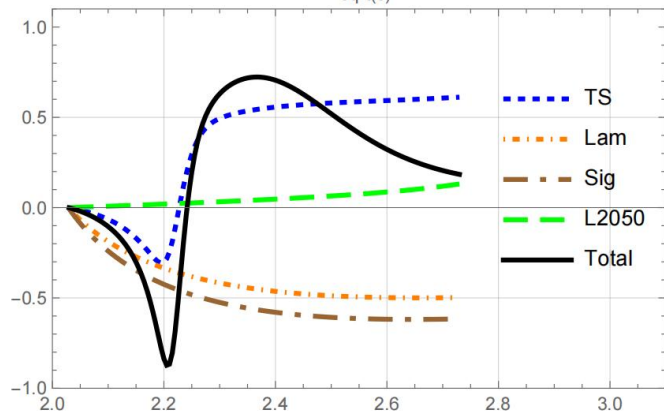
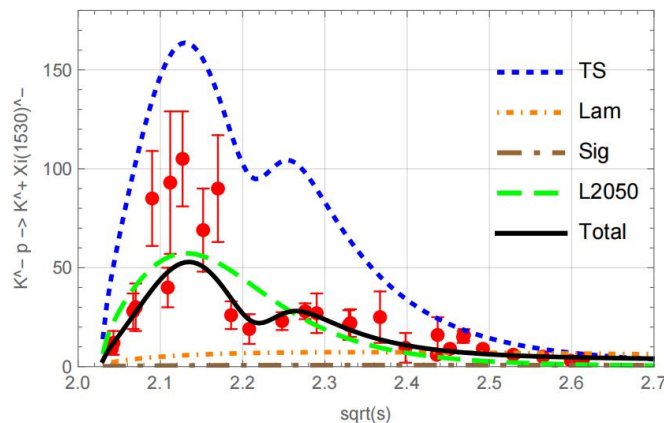


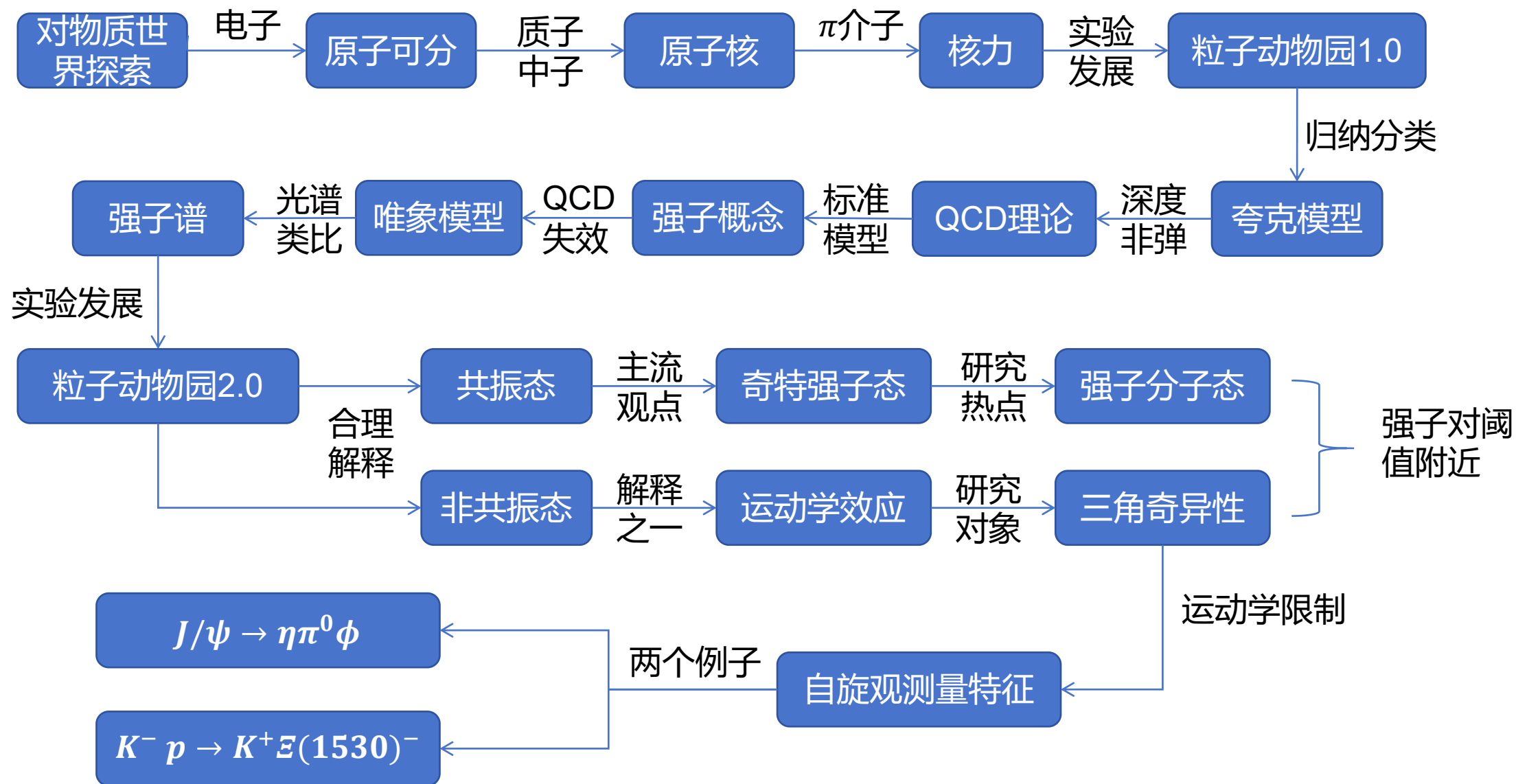
三角奇异性模型



$$\mathcal{M}_{IIB,j}^{\text{Total}} = e^{i\phi_j} \mathcal{M}^{\text{TS}} + \mathcal{M}_{\Lambda(1116)}^s + \mathcal{M}_{\Lambda(2050)}^s + \mathcal{M}_{\Sigma(1193)}^s + \mathcal{M}_{\Lambda(1116)}^u + \mathcal{M}_{\Lambda(2050)}^u + \mathcal{M}_{\Sigma(1193)}^u$$

Parameter	Value	Parameter	Value
$g_{\Lambda(1116)}$	-1.311×10^{-1}	m_R	2115.6 MeV
$g_{\Lambda(2050)}$	6.082×10^{-1}	Γ_R	360.76 MeV
$g_{\Sigma(1193)}$	2.356×10^{-1}	g_R	3.890×10^{-1}
ϕ_c	2.600	Λ_π	2721.3 MeV
ϕ_n	1.245	$\chi^2/d.o.f$	1.61





THANKS



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Tsinghua University