第一届介子束流物理研讨会

K介子束流强子物理理论研究现状

吴佳俊 (中国科学院大学)

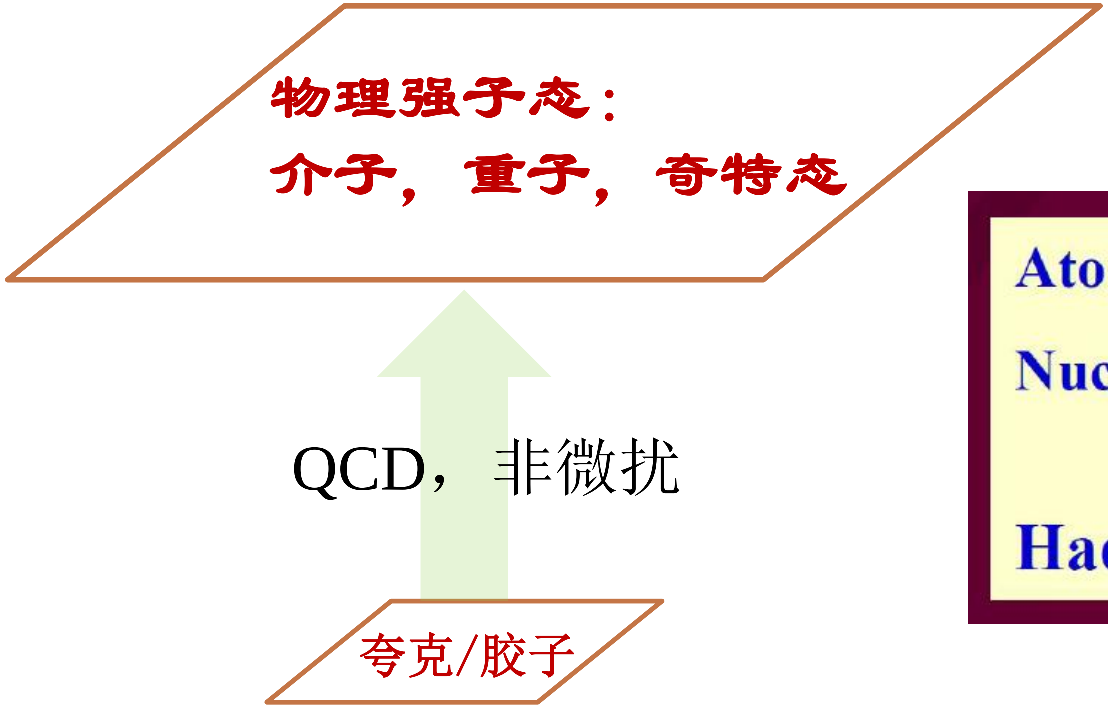
第一届介子束流物理研讨会 2024.12.29 兰州 中国科学院近代物理所

中国科学院大学
University of Chinese Academy of Sciences

目录

- 动机
- K介子束流实验数据
- K介子束流理论研究
- 小结和展望

动机



物理强子态：

介子， 重子， 奇特态

QCD，非微扰

夸克/胶子

强子谱？强子结构---强子内部的成分？

Atomic spectroscopy → Atomic Quantum Theory

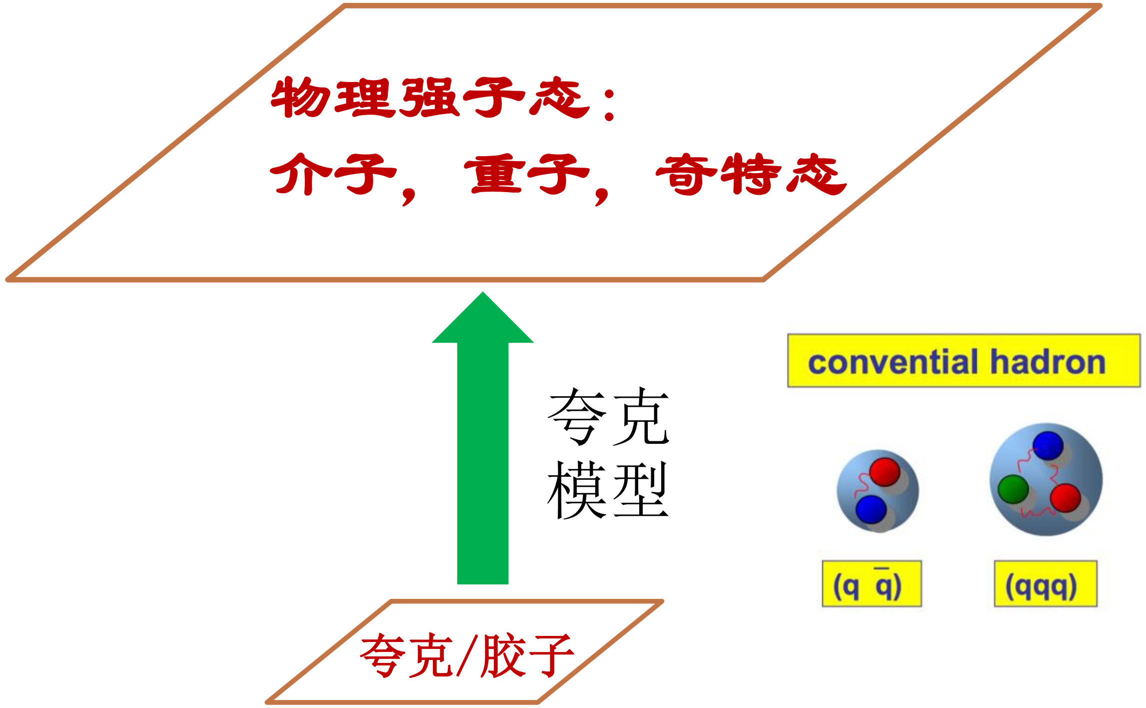
Nuclear spectroscopy → Shell Model &
Collective motion Model

Hadron spectroscopy → ?

来自邹冰松院士的PPT截图

背景介绍

强子谱？强子结构——强子内部的成分？

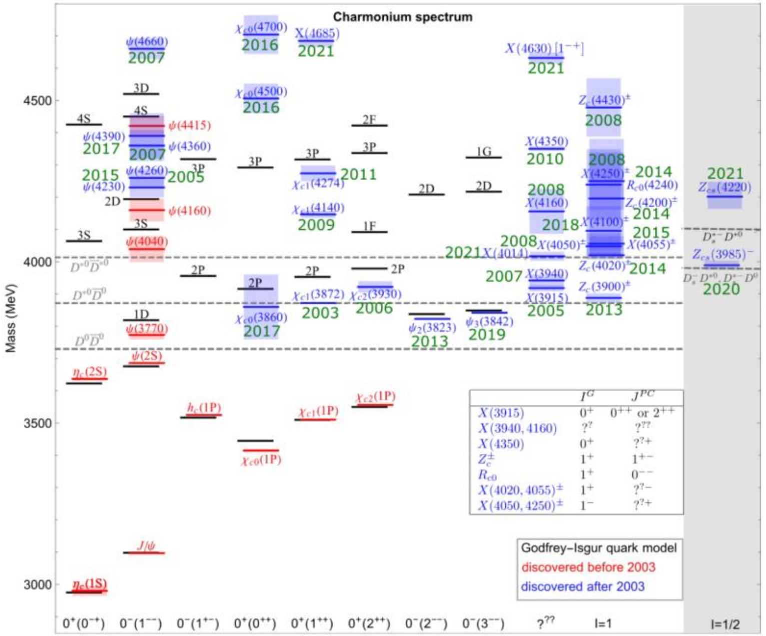


物理强子态：

介子，重子，奇特态

夸克模型

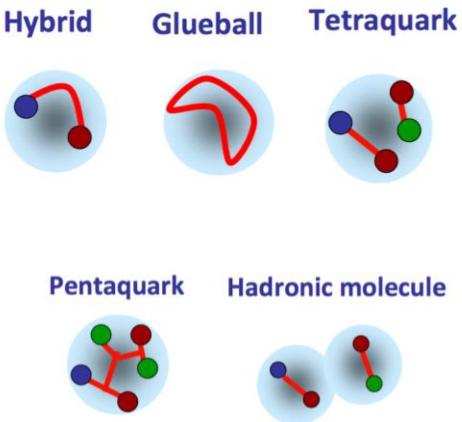
夸克/胶子



	I^G	J^{PC}
$X(3915)$	0^+	0^{++} or 2^{++}
$X(3940,4160)$	$?^?$	$?^{??}$
$X(4350)$	0^+	$?^{?+}$
$Z_c^\pm$	1^+	1^{+-}
R_{c0}	1^+	0^{--}
$X(4020,4055)^\pm$	1^+	$?^{?-}$
$X(4050,4250)^\pm$	1^-	$?^{?+}$

Godfrey–Isgur quark model
discovered before 2003
discovered after 2003

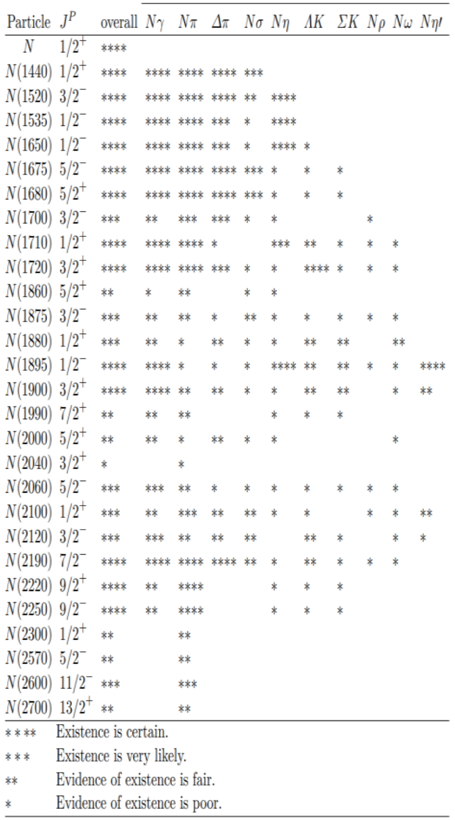
Exotic



UNQUENCHED quark model

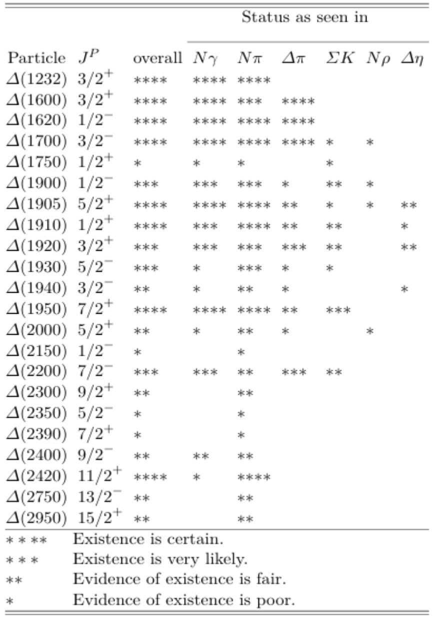
非淬火夸克模型

动机



Particle	J^P	overall	$N\gamma$	$N\pi$	$\Delta\pi$	$N\sigma$	$N\eta$	ΛK	ΣK	$N\rho$	$N\omega$	$N\eta'$
N	$1/2^+$	****										
$N(1440)$	$1/2^+$	****	****	****	****	***						
$N(1520)$	$3/2^-$	****	****	****	****	**	****					
$N(1535)$	$1/2^-$	****	****	****	***	*	****					
$N(1650)$	$1/2^-$	****	****	****	***	*	****	*				
$N(1675)$	$5/2^-$	****	****	****	****	***	*	*	*			
$N(1680)$	$5/2^+$	****	****	****	****	***	*	*	*			
$N(1700)$	$3/2^-$	***	**	***	***	*	*			*		
$N(1710)$	$1/2^+$	****	****	****	*		***	**	*	*	*	
$N(1720)$	$3/2^+$	****	****	****	***	*	*	****	*	*	*	
$N(1860)$	$5/2^+$	**	*	**		*	*					
$N(1875)$	$3/2^-$	***	**	**	*	**	*	*	*	*	*	
$N(1880)$	$1/2^+$	***	**	*	**	*	*	**	**		**	
$N(1895)$	$1/2^-$	****	****	*	*	*	****	**	**	*	*	****
$N(1900)$	$3/2^+$	****	****	**	**	*	*	**	**		*	**
$N(1990)$	$7/2^+$	**	**	**			*	*	*			
$N(2000)$	$5/2^+$	**	**	*	**	*	*				*	
$N(2040)$	$3/2^+$	*		*								
$N(2060)$	$5/2^-$	***	***	**	*	*	*	*	*	*	*	
$N(2100)$	$1/2^+$	***	**	***	**	**	*	*		*	*	**
$N(2120)$	$3/2^-$	***	***	**	**	**		**	*		*	*
$N(2190)$	$7/2^-$	****	****	****	****	**	*	**	*	*	*	
$N(2220)$	$9/2^+$	****	**	****			*	*	*			
$N(2250)$	$9/2^-$	****	**	****			*	*	*			
$N(2300)$	$1/2^+$	**		**								
$N(2570)$	$5/2^-$	**		**								
$N(2600)$	$11/2^-$	***		***								
$N(2700)$	$13/2^+$	**		**								

****	Existence is certain.
***	Existence is very likely.
**	Evidence of existence is fair.
*	Evidence of existence is poor.



			Status as seen in					
Particle	J^P	overall	$N\gamma$	$N\pi$	$\Delta\pi$	ΣK	$N\rho$	$\Delta\eta$
$\Delta(1232)$	$3/2^+$	****	****	****				
$\Delta(1600)$	$3/2^+$	****	****	***	****			
$\Delta(1620)$	$1/2^-$	****	****	****	****			
$\Delta(1700)$	$3/2^-$	****	****	****	****	*	*	
$\Delta(1750)$	$1/2^+$	*	*	*		*		
$\Delta(1900)$	$1/2^-$	***	***	***	*	**	*	
$\Delta(1905)$	$5/2^+$	****	****	****	**	*	*	**
$\Delta(1910)$	$1/2^+$	****	***	****	**	**		*
$\Delta(1920)$	$3/2^+$	***	***	***	***	**		**
$\Delta(1930)$	$5/2^-$	***	*	***	*	*		
$\Delta(1940)$	$3/2^-$	**	*	**	*			*
$\Delta(1950)$	$7/2^+$	****	****	****	**	***		
$\Delta(2000)$	$5/2^+$	**	*	**	*		*	
$\Delta(2150)$	$1/2^-$	*		*				
$\Delta(2200)$	$7/2^-$	***	***	**	***	**		
$\Delta(2300)$	$9/2^+$	**		**				
$\Delta(2350)$	$5/2^-$	*		*				
$\Delta(2390)$	$7/2^+$	*		*				
$\Delta(2400)$	$9/2^-$	**	**	**				
$\Delta(2420)$	$11/2^+$	****	*	****				
$\Delta(2750)$	$13/2^-$	**		**				
$\Delta(2950)$	$15/2^+$	**		**				

****	Existence is certain.
***	Existence is very likely.
**	Evidence of existence is fair.
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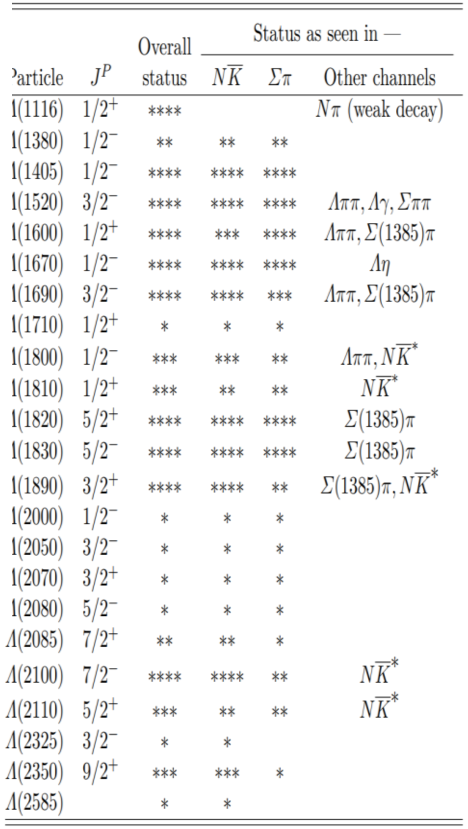
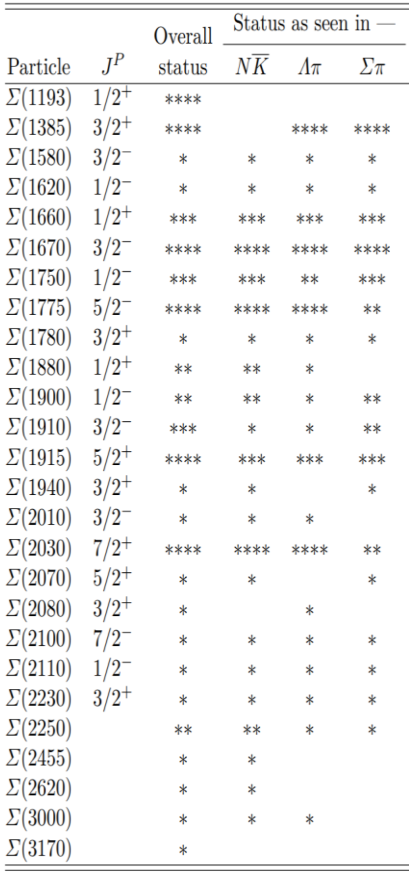
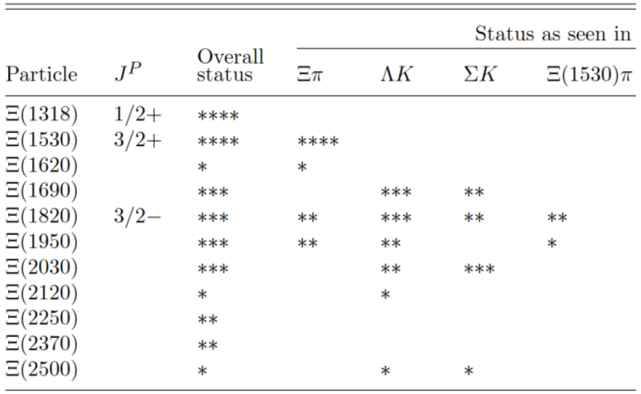


		Overall	Status as seen in —		
Particle	J^P	status	$N\overline{K}$	$\Sigma\pi$	Other channels
$\Lambda(1116)$	$1/2^+$	****			$N\pi$ (weak decay)
$\Lambda(1380)$	$1/2^-$	**	**	**	
$\Lambda(1405)$	$1/2^-$	****	****	****	
$\Lambda(1520)$	$3/2^-$	****	****	****	$\Lambda\pi\pi, \Lambda\gamma, \Sigma\pi\pi$
$\Lambda(1600)$	$1/2^+$	****	***	****	$\Lambda\pi\pi, \Sigma(1385)\pi$
$\Lambda(1670)$	$1/2^-$	****	****	****	$\Lambda\eta$
$\Lambda(1690)$	$3/2^-$	****	****	***	$\Lambda\pi\pi, \Sigma(1385)\pi$
$\Lambda(1710)$	$1/2^+$	*	*	*	
$\Lambda(1800)$	$1/2^-$	***	***	**	$\Lambda\pi\pi, N\overline{K}^*$
$\Lambda(1810)$	$1/2^+$	***	**	**	$N\overline{K}^*$
$\Lambda(1820)$	$5/2^+$	****	****	****	$\Sigma(1385)\pi$
$\Lambda(1830)$	$5/2^-$	****	****	****	$\Sigma(1385)\pi$
$\Lambda(1890)$	$3/2^+$	****	****	**	$\Sigma(1385)\pi, N\overline{K}^*$
$\Lambda(2000)$	$1/2^-$	*	*	*	
$\Lambda(2050)$	$3/2^-$	*	*	*	
$\Lambda(2070)$	$3/2^+$	*	*	*	
$\Lambda(2080)$	$5/2^-$	*	*	*	
$\Lambda(2085)$	$7/2^+$	**	**	*	
$\Lambda(2100)$	$7/2^-$	****	****	**	$N\overline{K}^*$
$\Lambda(2110)$	$5/2^+$	***	**	**	$N\overline{K}^*$
$\Lambda(2325)$	$3/2^-$	*	*		
$\Lambda(2350)$	$9/2^+$	***	***	*	
$\Lambda(2585)$		*	*		



		Overall	Status as seen in —		
Particle	J^P	status	$N\overline{K}$	$\Lambda\pi$	$\Sigma\pi$
$\Sigma(1193)$	$1/2^+$	****			
$\Sigma(1385)$	$3/2^+$	****		****	****
$\Sigma(1580)$	$3/2^-$	*	*	*	*
$\Sigma(1620)$	$1/2^-$	*	*	*	*
$\Sigma(1660)$	$1/2^+$	***	***	***	***
$\Sigma(1670)$	$3/2^-$	****	****	****	****
$\Sigma(1750)$	$1/2^-$	***	***	**	***
$\Sigma(1775)$	$5/2^-$	****	****	****	**
$\Sigma(1780)$	$3/2^+$	*	*	*	*
$\Sigma(1880)$	$1/2^+$	**	**	*	
$\Sigma(1900)$	$1/2^-$	**	**	*	**
$\Sigma(1910)$	$3/2^-$	***	*	*	**
$\Sigma(1915)$	$5/2^+$	****	***	***	***
$\Sigma(1940)$	$3/2^+$	*	*		*
$\Sigma(2010)$	$3/2^-$	*	*	*	
$\Sigma(2030)$	$7/2^+$	****	****	****	**
$\Sigma(2070)$	$5/2^+$	*	*		*
$\Sigma(2080)$	$3/2^+$	*		*	
$\Sigma(2100)$	$7/2^-$	*	*	*	*
$\Sigma(2110)$	$1/2^-$	*	*	*	*
$\Sigma(2230)$	$3/2^+$	*	*	*	*
$\Sigma(2250)$		**	**	*	*
$\Sigma(2455)$		*	*		
$\Sigma(2620)$		*	*		
$\Sigma(3000)$		*	*	*	
$\Sigma(3170)$		*			



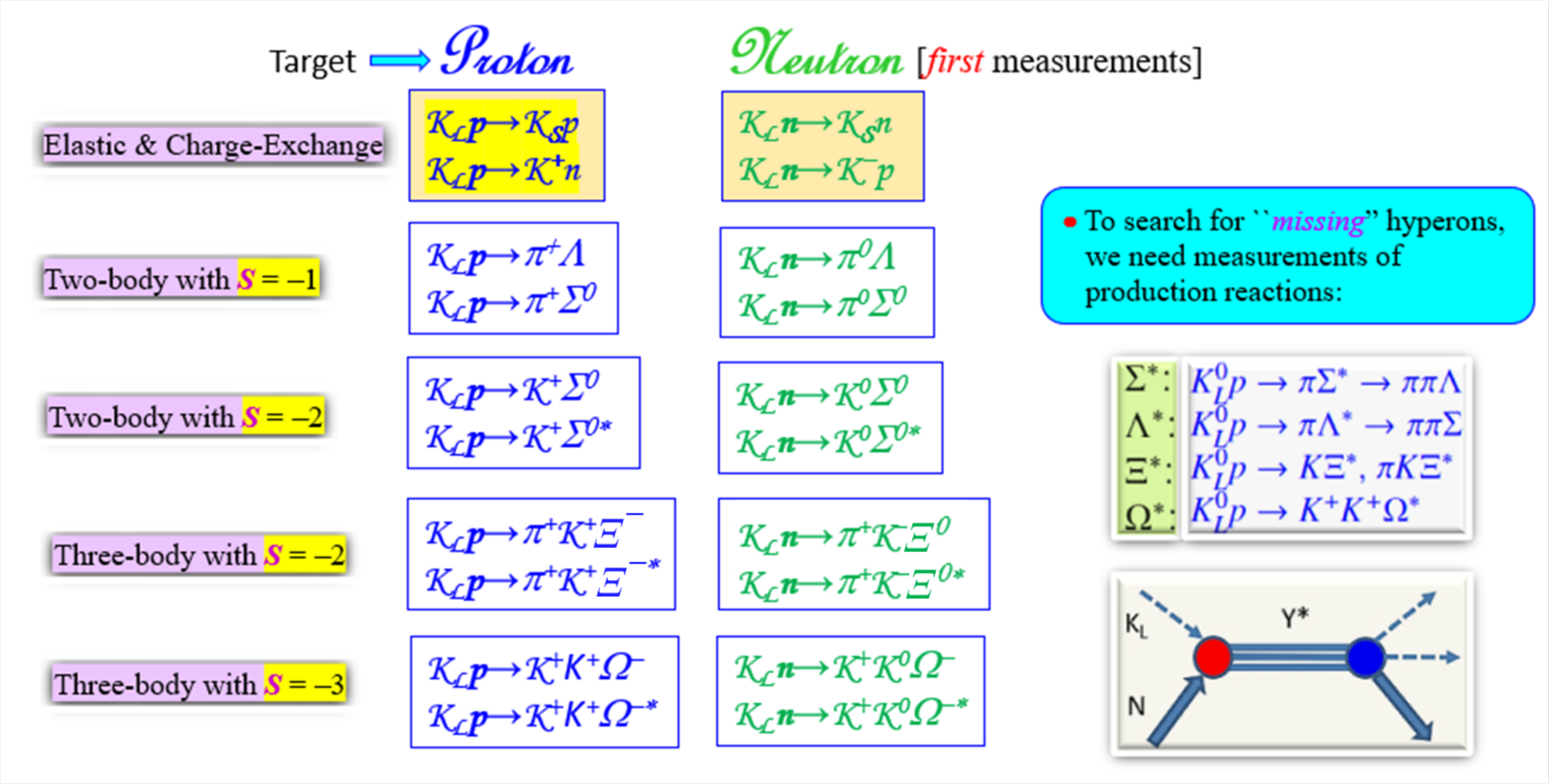
			Status as seen in			
Particle	J^P	Overall status	$\Xi\pi$	ΛK	ΣK	$\Xi(1530)\pi$
$\Xi(1318)$	$1/2+$	****				
$\Xi(1530)$	$3/2+$	****	****			
$\Xi(1620)$		*	*			
$\Xi(1690)$		***		***	**	
$\Xi(1820)$	$3/2-$	***	**	***	**	**
$\Xi(1950)$		***	**	**		*
$\Xi(2030)$		***		**	***	
$\Xi(2120)$		*		*		
$\Xi(2250)$		**				
$\Xi(2370)$		**				
$\Xi(2500)$		*		*	*	

Omega-	☆☆☆☆
Omega(2012)-	☆☆☆
Omega(2250)-	☆☆☆
Omega(2380)-	☆☆
Omega(2470)-	☆☆

三星以上/以下的，N^*，21/7个，Δ^*，12/10个，Λ^*, 14/9个，Σ^*, 9/17个, Ξ^* , 6/5个, Ω^* , 3/2个

夸克模型预言的小于3GeV的N^*至少多于64个！

动机



Target ⟹	Proton	Neutron [*first* measurements]
Elastic & Charge-Exchange	$K_L p \to K_S p$ $K_L p \to K^+ n$	$K_L n \to K_S n$ $K_L n \to K^- p$
Two-body with $S = -1$	$K_L p \to \pi^+ \Lambda$ $K_L p \to \pi^+ \Sigma^0$	$K_L n \to \pi^0 \Lambda$ $K_L n \to \pi^0 \Sigma^0$
Two-body with $S = -2$	$K_L p \to K^+ \Sigma^0$ $K_L p \to K^+ \Sigma^{0*}$	$K_L n \to K^0 \Sigma^0$ $K_L n \to K^0 \Sigma^{0*}$
Three-body with $S = -2$	$K_L p \to \pi^+ K^+ \Xi^-$ $K_L p \to \pi^+ K^+ \Xi^{-*}$	$K_L n \to \pi^+ K^- \Xi^0$ $K_L n \to \pi^+ K^- \Xi^{0*}$
Three-body with $S = -3$	$K_L p \to K^+ K^+ \Omega^-$ $K_L p \to K^+ K^+ \Omega^{-*}$	$K_L n \to K^+ K^0 \Omega^-$ $K_L n \to K^+ K^0 \Omega^{-*}$

- To search for ``*missing*'' hyperons, we need measurements of production reactions:

Σ^*: $K_L^0 p \to \pi \Sigma^* \to \pi\pi\Lambda$
Λ^*: $K_L^0 p \to \pi \Lambda^* \to \pi\pi\Sigma$
Ξ^*: $K_L^0 p \to K\Xi^*, \pi K \Xi^*$
Ω^*: $K_L^0 p \to K^+ K^+ \Omega^*$

三星以上/以下的，N^*，**21/7**个，Δ^*，**12/10**个，Λ^*, **14/9**个，Σ^*, **9/17**个, Ξ^* , **6/5**个，Ω^* , **3/2**个
夸克模型预言的小于3GeV的N^*至少多于**64**个！

动机

$$\gamma p \to KY^*,\quad \pi p \to KY^*,\quad e^+e^- \to Y\bar{Y}^*,\quad ep \to eKY^*,\quad pp \to KNY^*$$

问题：多强子末态带来的困扰！

$$K^-p \to Y^*$$

比较干净，不用考虑太多的末态相互作用

K介子束流实验数据

- 早期的实验，1986年之前 ISBN 3-540-l 8386-8 Springer-Verlag Berlin Heidelberg New York
  ISBN O-387-18386-8 Springer-Verlag New York Heidelberg Berlin

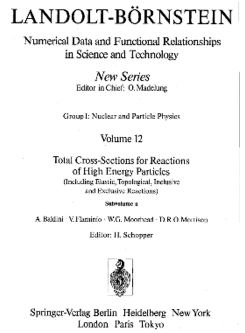
- 近期的实验， 2001-2009年BNL的Crystal Ball合作组

  PRC64(2001)055205, 68(2003)015206, 69(2004)042202, 70(2004)034605, 80(2009)025204, 80(2009)025204
  Phys.Lett.B 588 (2004) 29

- 现在的实验，J-PARC实验 H. Ohnishi, F. Sakuma, T. Takahashi，Particle and Nuclear Physics 113 (2020) 103773

- 未来的实验，Jlab的Hall D，中国HIAF？

  KLF Collaboration 2008.08215



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K介子束流实验数据

- 早期的实验，1986年之前

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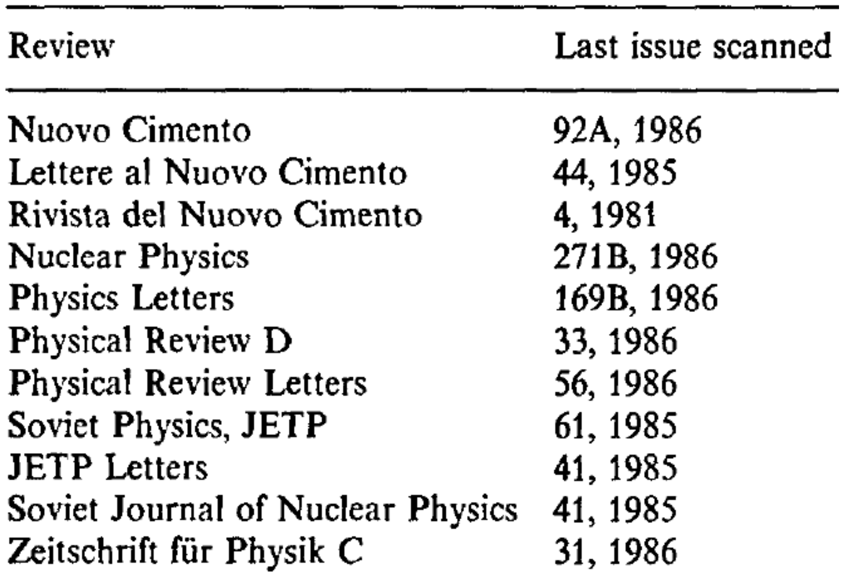
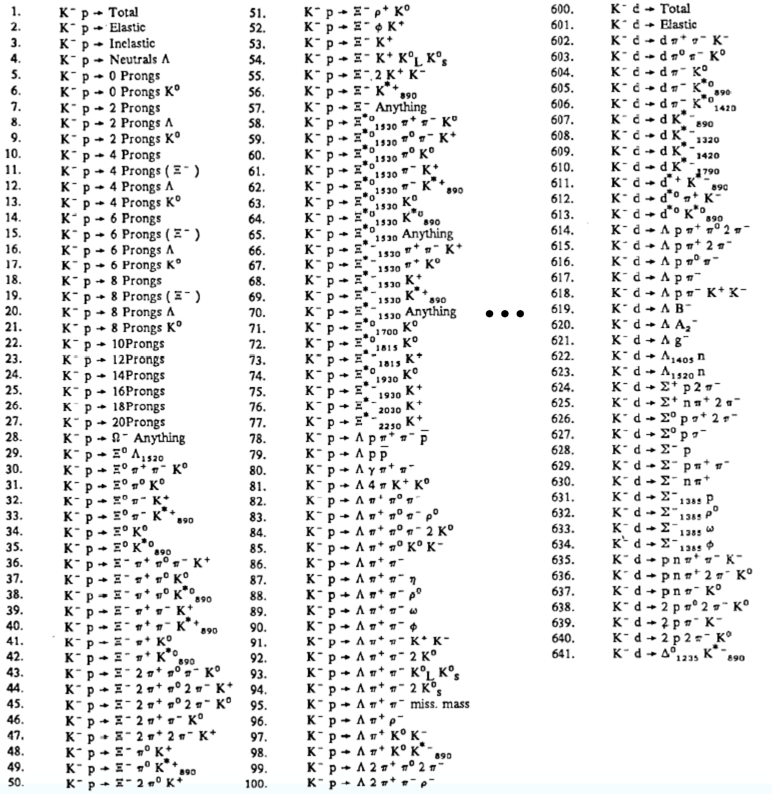


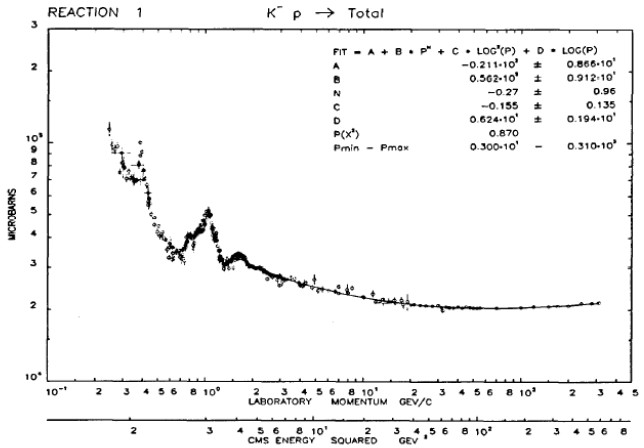
Review	Last issue scanned
Nuovo Cimento	92A, 1986
Lettere al Nuovo Cimento	44, 1985
Rivista del Nuovo Cimento	4, 1981
Nuclear Physics	271B, 1986
Physics Letters	169B, 1986
Physical Review D	33, 1986
Physical Review Letters	56, 1986
Soviet Physics, JETP	61, 1985
JETP Letters	41, 1985
Soviet Journal of Nuclear Physics	41, 1985
Zeitschrift für Physik C	31, 1986

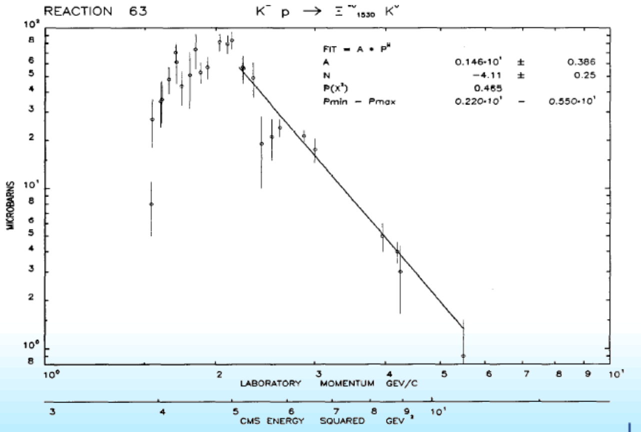


1. $K^- p \to$ Total
2. $K^- p \to$ Elastic
3. $K^- p \to$ Inelastic
4. $K^- p \to$ Neutrals Λ
5. $K^- p \to$ 0 Prongs
6. $K^- p \to$ 0 Prongs K^0
7. $K^- p \to$ 2 Prongs
8. $K^- p \to$ 2 Prongs Λ
9. $K^- p \to$ 2 Prongs K^0
10. $K^- p \to$ 4 Prongs
11. $K^- p \to$ 4 Prongs (Ξ^-)
12. $K^- p \to$ 4 Prongs Λ
13. $K^- p \to$ 4 Prongs K^0
14. $K^- p \to$ 6 Prongs
15. $K^- p \to$ 6 Prongs (Ξ^-)
16. $K^- p \to$ 6 Prongs Λ
17. $K^- p \to$ 6 Prongs K^0
18. $K^- p \to$ 8 Prongs
19. $K^- p \to$ 8 Prongs (Ξ^-)
20. $K^- p \to$ 8 Prongs Λ
21. $K^- p \to$ 8 Prongs K^0
22. $K^- p \to$ 10Prongs
23. $K^- p \to$ 12Prongs
24. $K^- p \to$ 14Prongs
25. $K^- p \to$ 16Prongs
26. $K^- p \to$ 18Prongs
27. $K^- p \to$ 20Prongs
28. $K^- p \to \Omega^-$ Anything
29. $K^- p \to \Xi^0 \Lambda_{1520}$
30. $K^- p \to \Xi^0 \pi^+ \pi^- K^0$
31. $K^- p \to \Xi^0 \pi^0 K^0$
32. $K^- p \to \Xi^0 \pi^- K^+$
33. $K^- p \to \Xi^0 \pi^- K^{*+}_{890}$
34. $K^- p \to \Xi^0 K^0$
35. $K^- p \to \Xi^0 K^{*0}_{890}$
36. $K^- p \to \Xi^- \pi^+ \pi^0 \pi^- K^+$
37. $K^- p \to \Xi^- \pi^+ \pi^0 K^0$
38. $K^- p \to \Xi^- \pi^+ \pi^0 K^{*0}_{890}$
39. $K^- p \to \Xi^- \pi^+ \pi^- K^+$
40. $K^- p \to \Xi^- \pi^+ \pi^- K^{*+}_{890}$
41. $K^- p \to \Xi^- \pi^+ K^0$
42. $K^- p \to \Xi^- \pi^+ K^{*0}_{890}$
43. $K^- p \to \Xi^- 2\pi^+ \pi^0 \pi^- K^0$
44. $K^- p \to \Xi^- 2\pi^+ \pi^0 2\pi^- K^+$
45. $K^- p \to \Xi^- 2\pi^+ \pi^0 2\pi^- K^0$
46. $K^- p \to \Xi^- 2\pi^+ \pi^- K^0$
47. $K^- p \to \Xi^- 2\pi^+ 2\pi^- K^+$
48. $K^- p \to \Xi^- \pi^0 K^+$
49. $K^- p \to \Xi^- \pi^0 K^{*+}_{890}$
50. $K^- p \to \Xi^- 2\pi^0 K^+$
51. $K^- p \to \Xi^- \rho^+ K^0$
52. $K^- p \to \Xi^- \phi K^+$
53. $K^- p \to \Xi^- K^+$
54. $K^- p \to \Xi^- K^+ K^0_L K^0_s$
55. $K^- p \to \Xi^- 2K^+ K^-$
56. $K^- p \to \Xi^- K^{*+}_{890}$
57. $K^- p \to \Xi^-$ Anything
58. $K^- p \to \Xi^{*0}_{1530} \pi^+ \pi^- K^0$
59. $K^- p \to \Xi^{*0}_{1530} \pi^0 \pi^- K^+$
60. $K^- p \to \Xi^{*0}_{1530} \pi^0 K^0$
61. $K^- p \to \Xi^{*0}_{1530} \pi^- K^+$
62. $K^- p \to \Xi^{*0}_{1530} \pi^- K^{*+}_{890}$
63. $K^- p \to \Xi^{*0}_{1530} K^0$
64. $K^- p \to \Xi^{*0}_{1530} K^{*0}_{890}$
65. $K^- p \to \Xi^{*0}_{1530}$ Anything
66. $K^- p \to \Xi^{*-}_{1530} \pi^+ \pi^- K^+$
67. $K^- p \to \Xi^{*-}_{1530} \pi^+ K^0$
68. $K^- p \to \Xi^{*-}_{1530} K^+$
69. $K^- p \to \Xi^{*-}_{1530} K^{*+}_{890}$
70. $K^- p \to \Xi^{*-}_{1530}$ Anything
71. $K^- p \to \Xi^{*0}_{1700} K^0$
72. $K^- p \to \Xi^{*0}_{1815} K^0$
73. $K^- p \to \Xi^{*-}_{1815} K^+$
74. $K^- p \to \Xi^{*0}_{1930} K^0$
75. $K^- p \to \Xi^{*-}_{1930} K^+$
76. $K^- p \to \Xi^{*-}_{2030} K^+$
77. $K^- p \to \Xi^{*-}_{2250} K^+$
78. $K^- p \to \Lambda p \pi^+ \pi^- \bar{p}$
79. $K^- p \to \Lambda p \bar{p}$
80. $K^- p \to \Lambda \gamma \pi^+ \pi^-$
81. $K^- p \to \Lambda 4\pi K^+ K^0$
82. $K^- p \to \Lambda \pi^+ \pi^0 \pi^-$
83. $K^- p \to \Lambda \pi^+ \pi^0 \pi^- \rho^0$
84. $K^- p \to \Lambda \pi^+ \pi^0 \pi^- 2K^0$
85. $K^- p \to \Lambda \pi^+ \pi^0 K^0 K^-$
86. $K^- p \to \Lambda \pi^+ \pi^-$
87. $K^- p \to \Lambda \pi^+ \pi^- \eta$
88. $K^- p \to \Lambda \pi^+ \pi^- \rho^0$
89. $K^- p \to \Lambda \pi^+ \pi^- \omega$
90. $K^- p \to \Lambda \pi^+ \pi^- \phi$
91. $K^- p \to \Lambda \pi^+ \pi^- K^+ K^-$
92. $K^- p \to \Lambda \pi^+ \pi^- 2K^0$
93. $K^- p \to \Lambda \pi^+ \pi^- K^0_L K^0_S$
94. $K^- p \to \Lambda \pi^+ \pi^- 2K^0_S$
95. $K^- p \to \Lambda \pi^+ \pi^-$ miss. mass
96. $K^- p \to \Lambda \pi^+ \rho^-$
97. $K^- p \to \Lambda \pi^+ K^0 K^-$
98. $K^- p \to \Lambda \pi^+ K^0 K^{*-}_{890}$
99. $K^- p \to \Lambda 2\pi^+ \pi^0 2\pi^-$
100. $K^- p \to \Lambda 2\pi^+ \pi^- \rho^-$

…

600. $K^- d \to$ Total
601. $K^- d \to$ Elastic
602. $K^- d \to d \pi^+ \pi^- K^-$
603. $K^- d \to d \pi^0 \pi^- K^0$
604. $K^- d \to d \pi^- K^0$
605. $K^- d \to d \pi^- K^{*0}_{890}$
606. $K^- d \to d \pi^- K^{*0}_{1420}$
607. $K^- d \to d K^{*-}_{890}$
608. $K^- d \to d K^{*-}_{1320}$
609. $K^- d \to d K^{*-}_{1420}$
610. $K^- d \to d K^{*-}_{1790}$
611. $K^- d \to d^{*+} K^{*-}_{890}$
612. $K^- d \to d^{*0} \pi^+ K^-$
613. $K^- d \to d^{*0} K^{*0}_{890}$
614. $K^- d \to \Lambda p \pi^+ \pi^0 2\pi^-$
615. $K^- d \to \Lambda p \pi^+ 2\pi^-$
616. $K^- d \to \Lambda p \pi^0 \pi^-$
617. $K^- d \to \Lambda p \pi^-$
618. $K^- d \to \Lambda p \pi^- K^+ K^-$
619. $K^- d \to \Lambda B^-$
620. $K^- d \to \Lambda A_2^-$
621. $K^- d \to \Lambda g^-$
622. $K^- d \to \Lambda_{1405} n$
623. $K^- d \to \Lambda_{1520} n$
624. $K^- d \to \Sigma^+ p 2\pi^-$
625. $K^- d \to \Sigma^+ n \pi^+ 2\pi^-$
626. $K^- d \to \Sigma^0 p \pi^+ 2\pi^-$
627. $K^- d \to \Sigma^0 p \pi^-$
628. $K^- d \to \Sigma^- p$
629. $K^- d \to \Sigma^- p \pi^+ \pi^-$
630. $K^- d \to \Sigma^- n \pi^+$
631. $K^- d \to \Sigma^-_{1385} p$
632. $K^- d \to \Sigma^-_{1385} \rho^0$
633. $K^- d \to \Sigma^-_{1385} \omega$
634. $K^- d \to \Sigma^-_{1385} \phi$
635. $K^- d \to p n \pi^+ \pi^- K^-$
636. $K^- d \to p n \pi^+ 2\pi^- K^0$
637. $K^- d \to p n \pi^- K^0$
638. $K^- d \to 2p \pi^0 2\pi^- K^0$
639. $K^- d \to 2p \pi^- K^-$
640. $K^- d \to 2p 2\pi^- K^0$
641. $K^- d \to \Delta^0_{1235} K^{*-}_{890}$

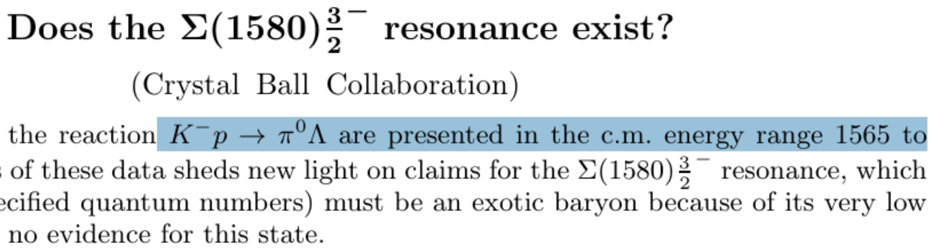




K介子束流实验数据

- **近期的实验，2001-2009年BNL的Crystal Ball合作组**

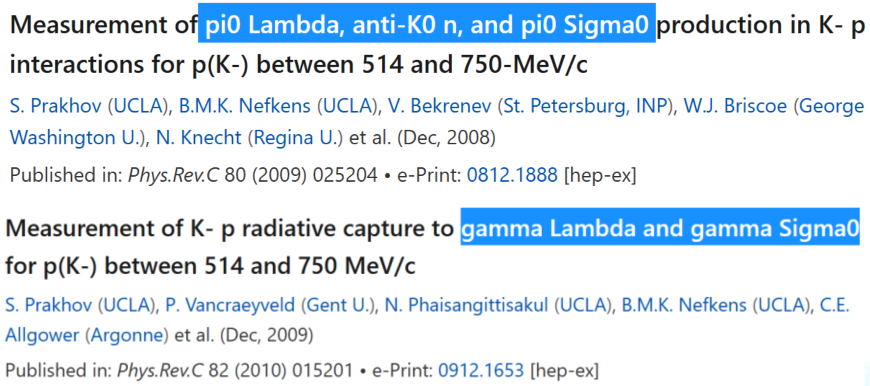
PRC64(2001)055205, 68(2003)015206, 69(2004)042202, 70(2004)034605, 80(2009)025204, 80(2009)025204
Phys.Lett.B 588 (2004) 29



Does the $\Sigma(1580)\frac{3}{2}^-$ resonance exist?

(Crystal Ball Collaboration)

Precise new data for the reaction $K^-p \to \pi^0\Lambda$ are presented in the c.m. energy range 1565 to 1600 MeV. Our analysis of these data sheds new light on claims for the $\Sigma(1580)\frac{3}{2}^-$ resonance, which (if it exists with the specified quantum numbers) must be an exotic baryon because of its very low mass. Our results show no evidence for this state.



Measurement of pi0 Lambda, anti-K0 n, and pi0 Sigma0 production in K- p interactions for p(K-) between 514 and 750-MeV/c

S. Prakhov (UCLA), B.M.K. Nefkens (UCLA), V. Bekrenev (St. Petersburg, INP), W.J. Briscoe (George Washington U.), N. Knecht (Regina U.) et al. (Dec, 2008)

Published in: *Phys.Rev.C* 80 (2009) 025204 • e-Print: 0812.1888 [hep-ex]

Measurement of K- p radiative capture to gamma Lambda and gamma Sigma0 for p(K-) between 514 and 750 MeV/c

S. Prakhov (UCLA), P. Vancraeyveld (Gent U.), N. Phaisangittisakul (UCLA), B.M.K. Nefkens (UCLA), C.E. Allgower (Argonne) et al. (Dec, 2009)

Published in: *Phys.Rev.C* 82 (2010) 015201 • e-Print: 0912.1653 [hep-ex]

Measurement of K- p --> eta Lambda near threshold

Crystal Ball Collaboration • A. Starostin (UCLA) et al. (2001)

Published in: *Phys.Rev.C* 64 (2001) 055205

Search for K- p ---> pi0 pi0 pi0 lambda from threshold to pK- = 750-MeV/c

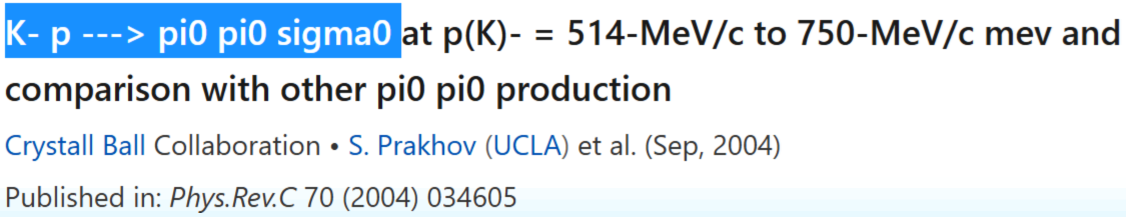
M. Borgh (UCLA), S. Prakhov (UCLA), B.M.K. Nefkens (UCLA), C.E. Allgower (Argonne), V. Bekrenev (St. Petersburg, INP) et al. (Jul, 2003)

Published in: *Phys.Rev.C* 68 (2003) 015206

Reaction K- p ---> pi0 pi0 lambda from pK- = 514-MeV/c to 750-MeV/c

S. Prakhov (UCLA), B.M.K. Nefkens (UCLA), C.E. Allgower (Argonne), V. Bekrenev (St. Petersburg, INP), W.J. Briscoe (George Washington U.) et al. (May, 2004)

Published in: *Phys.Rev.C* 69 (2004) 042202



K- p ---> pi0 pi0 sigma0 at p(K)- = 514-MeV/c to 750-MeV/c mev and comparison with other pi0 pi0 production

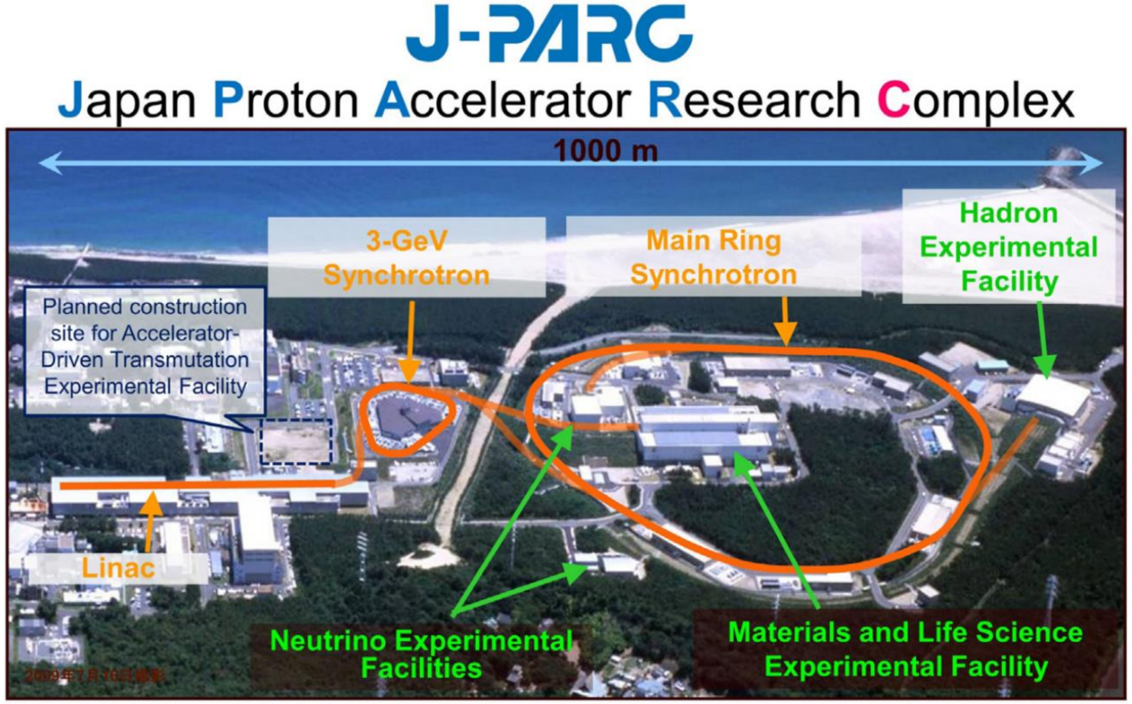
Crystall Ball Collaboration • S. Prakhov (UCLA) et al. (Sep, 2004)

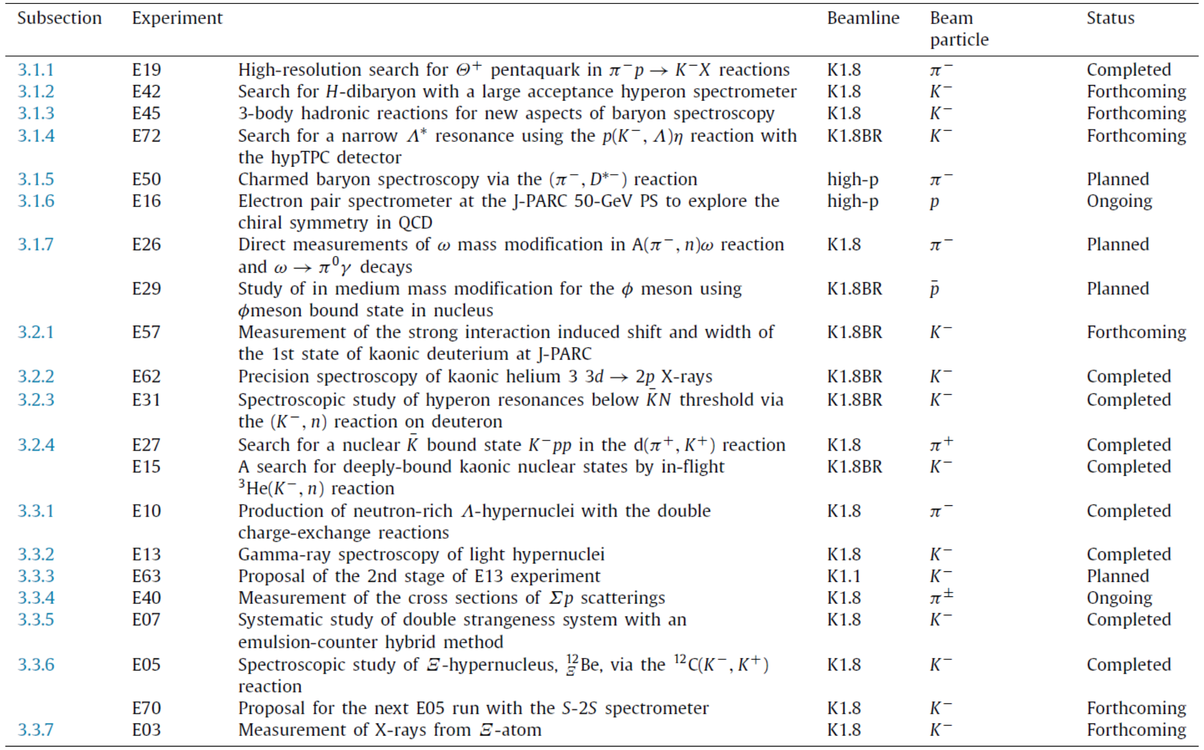
Published in: *Phys.Rev.C* 70 (2004) 034605

K介子束流实验数据

- 现在的实验，J-PARC实验

H. Ohnishi, F. Sakuma, T. Takahashi，Particle and Nuclear Physics 113 (2020) 103773
参考王晓云老师的报告

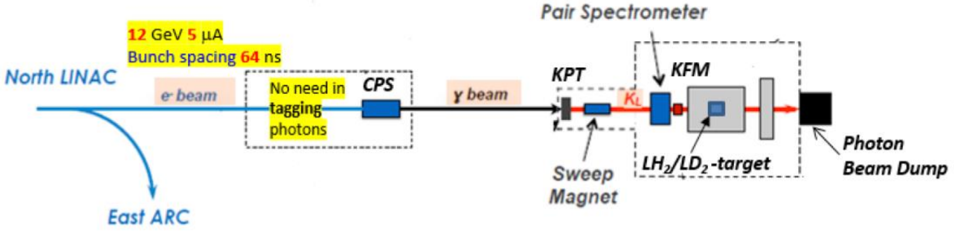




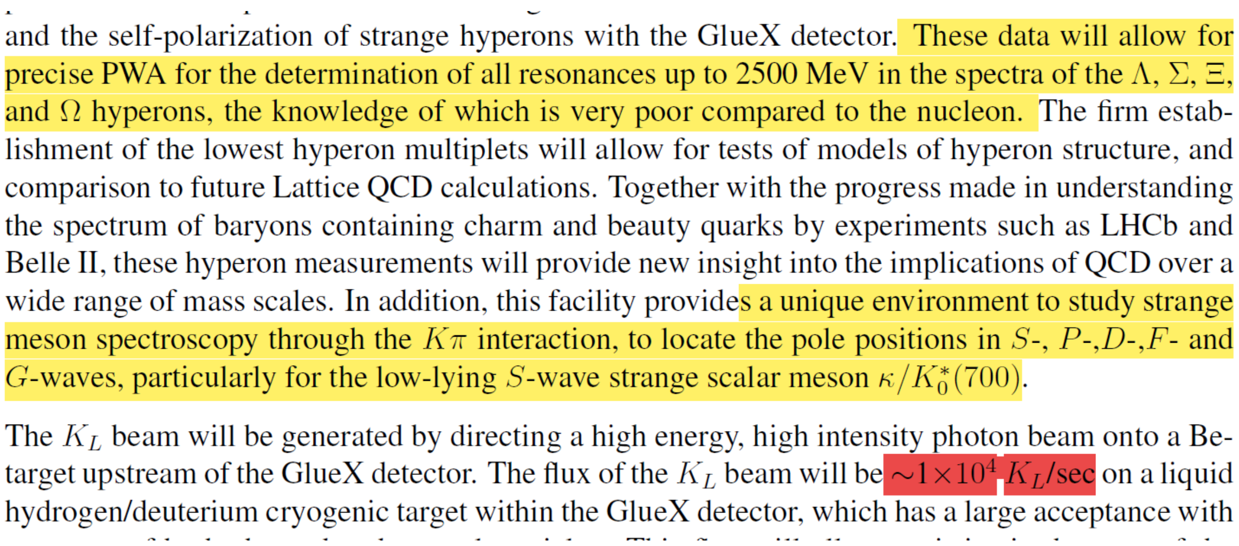
Subsection	Experiment		Beamline	Beam particle	Status
3.1.1	E19	High-resolution search for Θ^+ pentaquark in $\pi^- p \rightarrow K^- X$ reactions	K1.8	π^-	Completed
3.1.2	E42	Search for H-dibaryon with a large acceptance hyperon spectrometer	K1.8	K^-	Forthcoming
3.1.3	E45	3-body hadronic reactions for new aspects of baryon spectroscopy	K1.8	K^-	Forthcoming
3.1.4	E72	Search for a narrow Λ^* resonance using the $p(K^-, \Lambda)\eta$ reaction with the hypTPC detector	K1.8BR	K^-	Forthcoming
3.1.5	E50	Charmed baryon spectroscopy via the (π^-, D^{*-}) reaction	high-p	π^-	Planned
3.1.6	E16	Electron pair spectrometer at the J-PARC 50-GeV PS to explore the chiral symmetry in QCD	high-p	p	Ongoing
3.1.7	E26	Direct measurements of ω mass modification in A$(\pi^-, n)\omega$ reaction and $\omega \rightarrow \pi^0\gamma$ decays	K1.8	π^-	Planned
	E29	Study of in medium mass modification for the ϕ meson using ϕmeson bound state in nucleus	K1.8BR	$\bar{p}$	Planned
3.2.1	E57	Measurement of the strong interaction induced shift and width of the 1st state of kaonic deuterium at J-PARC	K1.8BR	K^-	Forthcoming
3.2.2	E62	Precision spectroscopy of kaonic helium 3 $3d \rightarrow 2p$ X-rays	K1.8BR	K^-	Completed
3.2.3	E31	Spectroscopic study of hyperon resonances below $\bar{K}N$ threshold via the (K^-, n) reaction on deuteron	K1.8BR	K^-	Completed
3.2.4	E27	Search for a nuclear $\bar{K}$ bound state K^-pp in the d(π^+, K^+) reaction	K1.8	π^+	Completed
	E15	A search for deeply-bound kaonic nuclear states by in-flight ^{3}He(K^-, n) reaction	K1.8BR	K^-	Completed
3.3.1	E10	Production of neutron-rich Λ-hypernuclei with the double charge-exchange reactions	K1.8	π^-	Completed
3.3.2	E13	Gamma-ray spectroscopy of light hypernuclei	K1.8	K^-	Completed
3.3.3	E63	Proposal of the 2nd stage of E13 experiment	K1.1	K^-	Planned
3.3.4	E40	Measurement of the cross sections of Σp scatterings	K1.8	$\pi^\pm$	Ongoing
3.3.5	E07	Systematic study of double strangeness system with an emulsion-counter hybrid method	K1.8	K^-	Completed
3.3.6	E05	Spectroscopic study of Ξ-hypernucleus, $^{12}_{\Xi}$Be, via the ^{12}C(K^-, K^+) reaction	K1.8	K^-	Completed
	E70	Proposal for the next E05 run with the S-2S spectrometer	K1.8	K^-	Forthcoming
3.3.7	E03	Measurement of X-rays from Ξ-atom	K1.8	K^-	Forthcoming

K介子束流实验数据

- 未来的实验，Jlab的Hall D，中国HIAF？

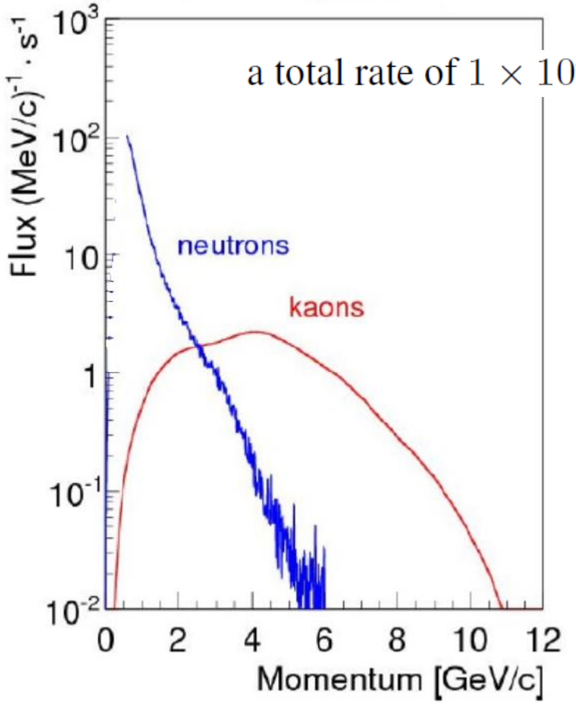


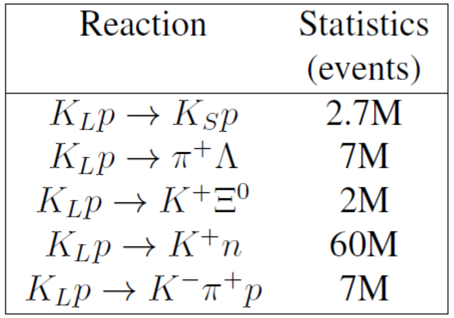
KLF Collaboration 2008.08215


and the self-polarization of strange hyperons with the GlueX detector. These data will allow for precise PWA for the determination of all resonances up to 2500 MeV in the spectra of the Λ, Σ, Ξ, and Ω hyperons, the knowledge of which is very poor compared to the nucleon. The firm establishment of the lowest hyperon multiplets will allow for tests of models of hyperon structure, and comparison to future Lattice QCD calculations. Together with the progress made in understanding the spectrum of baryons containing charm and beauty quarks by experiments such as LHCb and Belle II, these hyperon measurements will provide new insight into the implications of QCD over a wide range of mass scales. In addition, this facility provides a unique environment to study strange meson spectroscopy through the $K\pi$ interaction, to locate the pole positions in S-, P-,D-,F- and G-waves, particularly for the low-lying S-wave strange scalar meson $\kappa/K_0^*(700)$.

The K_L beam will be generated by directing a high energy, high intensity photon beam onto a Be-target upstream of the GlueX detector. The flux of the K_L beam will be $\sim 1\times10^4$ K_L/sec on a liquid hydrogen/deuterium cryogenic target within the GlueX detector, which has a large acceptance with

a total rate of 1×10^4 K_L/sec and 6.6×10^5 n/sec.



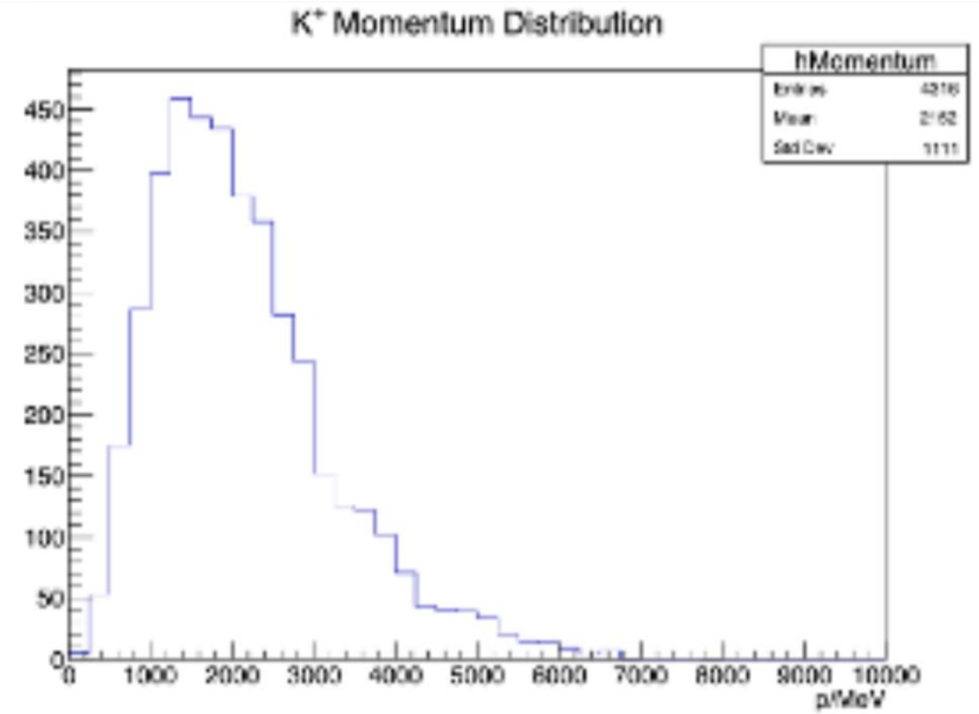


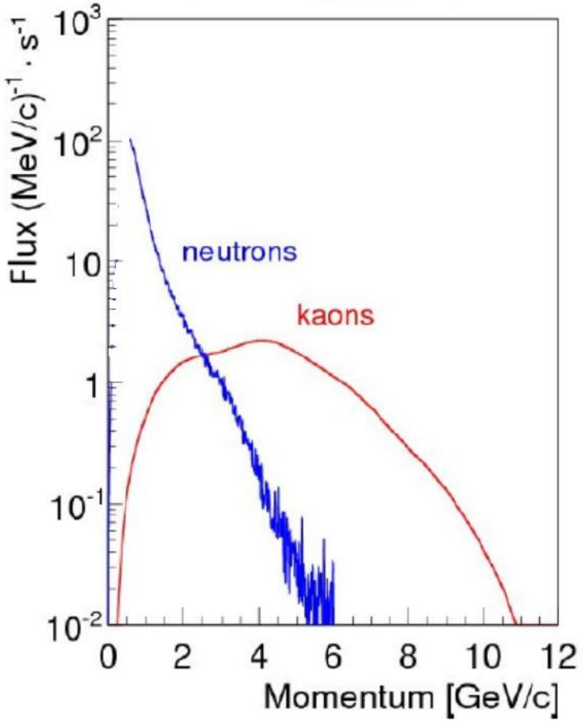
Reaction	Statistics (events)
$K_Lp \to K_Sp$	2.7M
$K_Lp \to \pi^+\Lambda$	7M
$K_Lp \to K^+\Xi^0$	2M
$K_Lp \to K^+n$	60M
$K_Lp \to K^-\pi^+p$	7M

K介子束流实验数据

- 未来的实验，Jlab的Hall D，中国HIAF？

KLF Collaboration 2008.08215





优势？

流强高1–2个量级

K介子束流理论研究

$$\bar{K}N \rightarrow \bar{K}N, \pi\Lambda, \eta\Lambda, \pi\Sigma, \eta\Sigma, K\Xi, \ldots$$

1. 树图阶的分波分析

Jia-Jun Wu,S. Dulat,B.S. Zou, Phys.Rev.C 81 (2010) 045210
Puze Gao, B.S. Zou, A. Sibirtsev, Nucl.Phys.A 867 (2011) 41-51,
Puze Gao, Jun Shi, B.S. Zou Phys.Rev.C 86 (2012) 025201
Jun Shi, B.S. Zou Phys.Rev.C 91 (2015) 3, 035202
B. C. Liu and J. J. Xie, Phys. Rev. C 85, 038201 (2012); Phys. Rev. C 86, 055202 (2012)
Li-Ye Xiao, Xian-Hui Zhong,Phys.Rev.C 88 (2013) 6, 065201
Xian-Hui Zhong, Qiang Zhao, Phys.Rev.C 88 (2013) 015208
Jun Shi，Long-Cheng Gui, Jian Liang，and Guoming Liu， 2305.01852 [hep-ph]

[1] R. Armenteros *et al.*, Nucl. Phys. B **14**, 91 (1969).
[2] B. Conforto *et al.*, Nucl. Phys. B **34**, 41 (1971).
[3] A. J. Van Horn, Nucl. Phys. B **87**, 145 (1975).
[4] R. J. Hemingway *et al.*, Nucl. Phys. B **91**, 12 (1975).
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[6] G. P. Gopal *et al.*, Nucl. Phys. B **119**, 362 (1977).

2. 耦合道分波分析

M. Matveev，A.V. Sarantsev，V.A. Nikonov，A.V. Anisovich，U. Thoma Eur.Phys.J.A 55 (2019) 10, 179
H. Kamano, S. X. Nakamura, T.-S. H. Lee and T. Sato, PRC 90 (2014) 065204， 92 (2015) 025205
Zhang,J. Tulpan,M. Shrestha,D.M. Manley，Phys.Rev.C 88 (2013) 3, 035204

Zhan-Wei Liu, Jonathan M.M. Hall, Derek B. Leinweber, Anthony W. Thomas，Jia-Jun Wu，
***Phys.Rev.D* 95 (2017) 1, 014506， Phys.Lett.B 808 (2020) 135652**

K介子束流理论研究

Analysis of the new Crystal Ball data on $K^-p \to \pi^0\Lambda$ reaction with beam momenta of $514 \sim 750$ MeV/c

Puze Gao, B.S. Zou

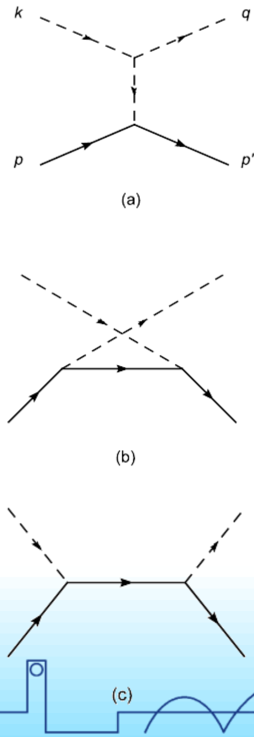
Σ Resonances from $K^-N \to \pi\Lambda$ reactions with a center of mass energy from 1550 to 1676 MeV

Puze Gao^a, Jun Shi^a, B. S. Zou^{a,b}

$$\bar{K}N \to \pi\Lambda$$

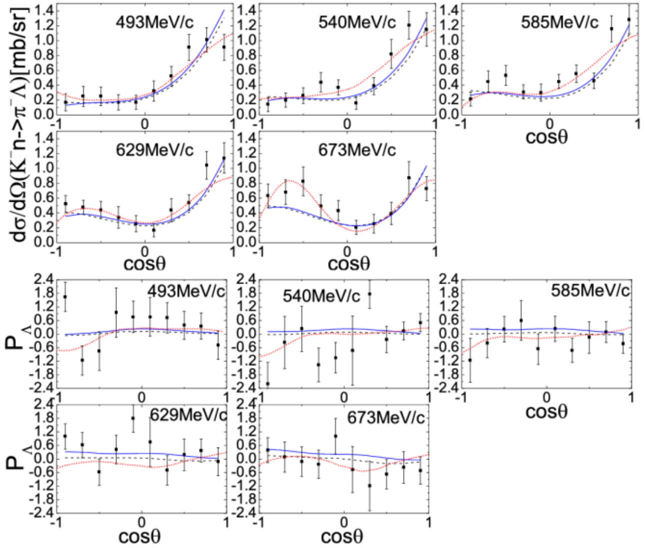
1. 树图阶的分波分析

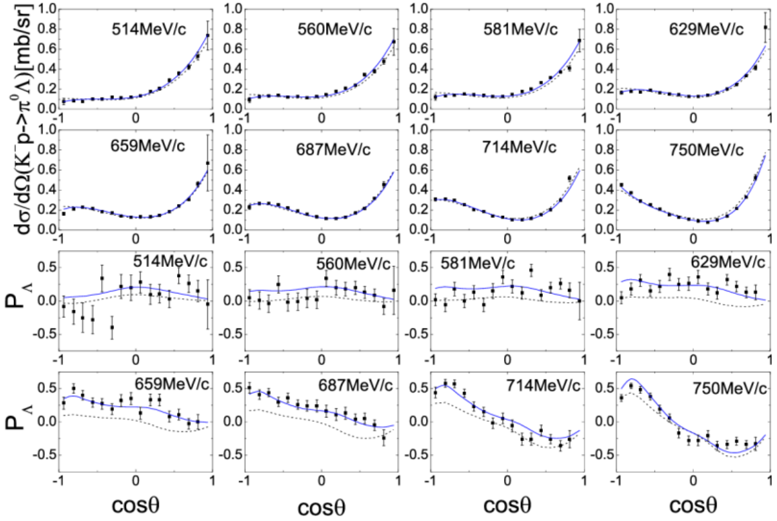
Puze Gao, B.S. Zou, A. Sibirtsev, Nucl.Phys.A 867 (2011) 41-51,
Puze Gao, Jun Shi, B.S. Zou Phys.Rev.C 86 (2012) 025201



$$\begin{aligned}
\mathcal{L}_{K^*K\pi} &= ig_{K^*K\pi}K^*_\mu(\pi\cdot\tau\partial^\mu K - \partial^\mu\pi\cdot\tau K) \\
\mathcal{L}_{K^*N\Lambda} &= -g_{K^*N\Lambda}\overline{\Lambda}(\gamma_\mu K^{*\mu} \\
&\quad -\frac{\kappa_{K^*N\Lambda}}{2M_N}\sigma_{\mu\nu}\partial^\nu K^{*\mu})N \\
\mathcal{L}_{\pi NN} &= \frac{g_{\pi NN}}{2M_N}\overline{N}\gamma^\mu\gamma_5\partial_\mu\pi\cdot\tau N \\
\mathcal{L}_{KN\Lambda} &= \frac{g_{KN\Lambda}}{M_N+M_\Lambda}\overline{N}\gamma^\mu\gamma_5\Lambda\partial_\mu K + H.c. \\
\mathcal{L}_{KN\Sigma(\frac{1}{2}^+)} &= \frac{g_{KN\Sigma}}{M_N+M_\Sigma}\partial_\mu\overline{K\Sigma}\cdot\tau\gamma^\mu\gamma_5 N + H.c. \\
\mathcal{L}_{\Sigma(\frac{1}{2}^+)\Lambda\pi} &= \frac{g_{\Sigma\Lambda\pi}}{M_\Lambda+M_\Sigma}\overline{\Lambda}\gamma^\mu\gamma_5\partial_\mu\pi\cdot\Sigma + H.c. \\
\mathcal{L}_{KN\Sigma(\frac{1}{2}^-)} &= -ig_{KN\Sigma}\overline{K\Sigma}\cdot\tau N + H.c. \\
\mathcal{L}_{\Lambda\pi\Sigma(\frac{1}{2}^-)} &= -ig_{\Lambda\pi\Sigma}\overline{\Sigma}\Lambda\pi + H.c. \\
\mathcal{L}_{KN\Sigma(\frac{3}{2}^+)} &= \frac{f_{KN\Sigma}}{m_K}\partial_\mu\overline{K\Sigma}^\mu\cdot\tau N + H.c. \\
\mathcal{L}_{\Sigma(\frac{3}{2}^+)\Lambda\pi} &= \frac{f_{\Sigma\Lambda\pi}}{m_\pi}\partial_\mu\overline{\pi}\cdot\overline{\Sigma}^\mu\Lambda + H.c. \\
\mathcal{L}_{KN\Sigma(\frac{3}{2}^-)} &= \frac{f_{KN\Sigma}}{m_K}\partial_\mu\overline{K\Sigma}^\mu\cdot\tau\gamma_5 N + H.c. \\
\mathcal{L}_{\Sigma(\frac{3}{2}^-)\Lambda\pi} &= \frac{f_{\Sigma\Lambda\pi}}{m_\pi}\partial_\mu\pi\overline{\Sigma}^\mu\gamma_5\Lambda + H.c. \\
\mathcal{L}_{KN\Sigma(\frac{5}{2}^-)} &= g_{KN\Sigma}\partial_\mu\partial_\nu\overline{K\Sigma}^{\mu\nu}\cdot\tau N + H.c. \\
\mathcal{L}_{\Sigma(\frac{5}{2}^-)\Lambda\pi} &= g_{\Lambda\pi\Sigma}\partial_\mu\partial_\nu\pi\cdot\overline{\Sigma}^{\mu\nu}\Lambda + H.c.
\end{aligned}$$

亮点：利用同位旋筛子细致研究Σ重子





拟合策略和结果，Σ(1189), Σ(1385),Σ(1670) 和 Σ(1775)总是包括，发现 Σ(1/2 +)的质量在1633 MeV宽度是120 MeV有重要贡献，但是Σ(1620)1/2-似乎不需要，该工作后Σ(1620)1/2-从两星粒子降为一星粒子

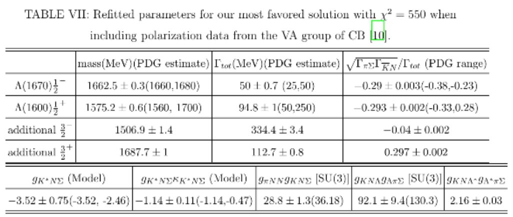


TABLE VII: Refitted parameters for our most favored solution with $\chi^2 = 550$ when including polarization data from the VA group of CB [10].

	mass(MeV)(PDG estimate)	Γ_{tot}(MeV)(PDG estimate)	$\sqrt{\Gamma_{\pi\Sigma}\Gamma_{\overline{K}N}}/\Gamma_{tot}$ (PDG range)
$\Lambda(1670)\frac{1}{2}^-$	1662.5 ± 0.3(1660,1680)	50 ± 0.7 (25,50)	-0.29 ± 0.003(-0.38,-0.23)
$\Lambda(1600)\frac{1}{2}^+$	1575.2 ± 0.6(1560, 1700)	94.8 ± 1(50,250)	-0.293 ± 0.002(-0.33,0.28)
additional $\frac{3}{2}^-$	1506.9 ± 1.4	334.4 ± 3.4	-0.04 ± 0.002
additional $\frac{3}{2}^+$	1687.7 ± 1	112.7 ± 0.8	0.297 ± 0.002

$g_{K^*N\Sigma}$ (Model)	$g_{K^*N\Sigma}\kappa_{K^*N\Sigma}$ (Model)	$g_{\pi NN}g_{KN\Sigma}$ [SU(3)]	$g_{KN\Lambda}g_{\Lambda\pi\Sigma}$ [SU(3)]	$g_{KN\Lambda^*}g_{\Lambda^*\pi\Sigma}$
-3.52 ± 0.75(-3.52, -2.46)	-1.14 ± 0.11(-1.14,-0.47)	28.8 ± 1.3(36.18)	92.1 ± 9.4(130.3)	2.16 ± 0.03

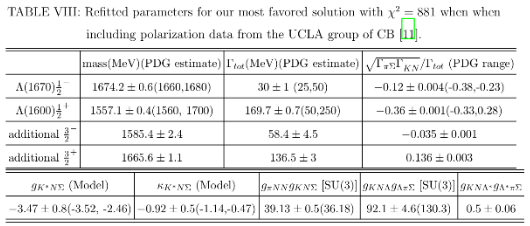


TABLE VIII: Refitted parameters for our most favored solution with $\chi^2 = 881$ when when including polarization data from the UCLA group of CB [11].

	mass(MeV)(PDG estimate)	Γ_{tot}(MeV)(PDG estimate)	$\sqrt{\Gamma_{\pi\Sigma}\Gamma_{\overline{K}N}}/\Gamma_{tot}$ (PDG range)
$\Lambda(1670)\frac{1}{2}^-$	1674.2 ± 0.6(1660,1680)	30 ± 1 (25,50)	-0.12 ± 0.004(-0.38,-0.23)
$\Lambda(1600)\frac{1}{2}^+$	1557.1 ± 0.4(1560, 1700)	169.7 ± 0.7(50,250)	-0.36 ± 0.001(-0.33,0.28)
additional $\frac{3}{2}^-$	1585.4 ± 2.4	58.4 ± 4.5	-0.035 ± 0.001
additional $\frac{3}{2}^+$	1665.6 ± 1.1	136.5 ± 3	0.136 ± 0.003

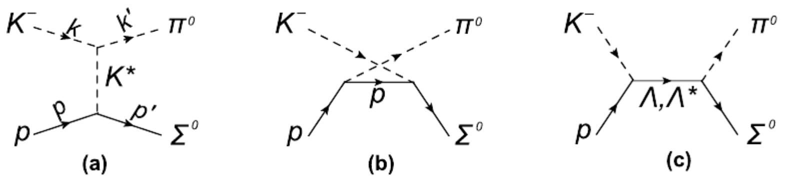
$g_{K^*N\Sigma}$ (Model)	$\kappa_{K^*N\Sigma}$ (Model)	$g_{\pi NN}g_{KN\Sigma}$ [SU(3)]	$g_{KN\Lambda}g_{\Lambda\pi\Sigma}$ [SU(3)]	$g_{KN\Lambda^*}g_{\Lambda^*\pi\Sigma}$
-3.47 ± 0.8(-3.52, -2.46)	-0.92 ± 0.5(-1.14,-0.47)	39.13 ± 0.5(36.18)	92.1 ± 4.6(130.3)	0.5 ± 0.06

K介子束流理论研究

$$\overline{K}N \rightarrow \pi^0\Sigma^0$$

1. 树图阶的分波分析

Jun Shi, B.S. Zou Phys.Rev.C 91 (2015) 3, 035202

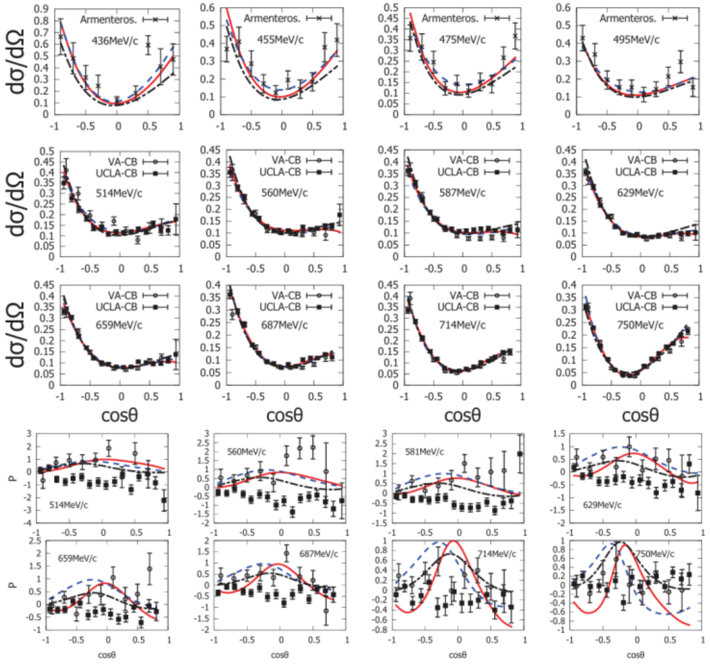


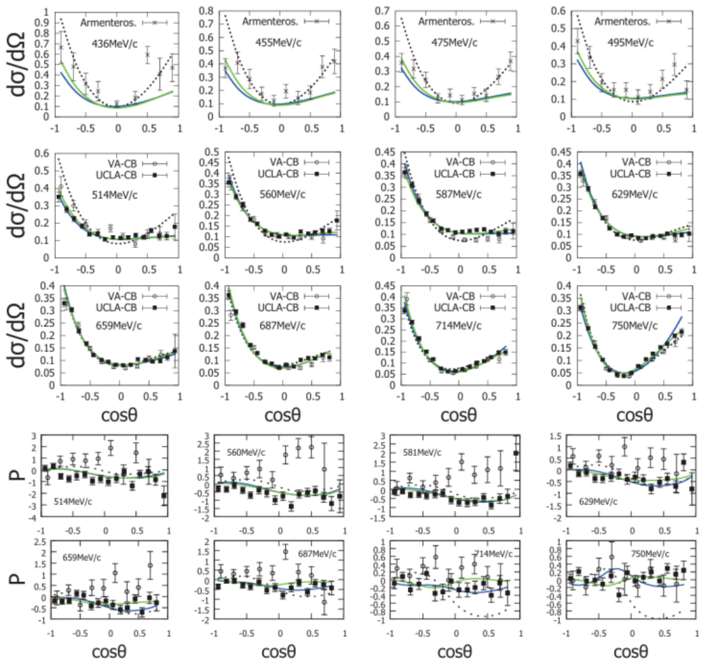
除了在这个能量范围内已经建立良好的PDG 4星Λ共振外，PDG中列为3星共振的Λ(1600)1/2+共振被发现确实是必需的。此外，有强有力的证据表明存在一个新的Λ(3/2+)共振约在1680 MeV附近，替换掉宽的Λ(3/2-) 。

Analysis of the Crystal Ball data on $K^-p \rightarrow \pi^0\Sigma^0$ reaction with center-of-mass energies of $1536 \sim 1676$ MeV

Jun Shi[1] and Bing-Song Zou[2,1]

亮点：利用同位旋筛子细致研究Λ重子





中国科学院大学
University of Chinese Academy of Sciences

K介子束流理论研究

$\bar{K}N \rightarrow \eta\Lambda$

$K^-p \rightarrow \eta\Lambda$ reaction in an effective Lagrangian model

Bo-Chao Liu[1,*] and Ju-Jun Xie[2,3,†]

[1] *Department of Applied Physics, Xi'an Jiaotong University, Xi'an, Shanxi 710049, China*
[2] *Department of Physics, Zhengzhou University, Zhengzhou, Henan 450001, China*
[3] *Instituto de Física Corpuscular (IFIC), Centro Mixto CSIC-Universidad de Valencia, Institutos de Investigación de Paterna, Aptd. 22085, E-46071 Valencia, Spain*

Evidence for a narrow D_{03} state in $K^-p \rightarrow \eta\Lambda$ near threshold

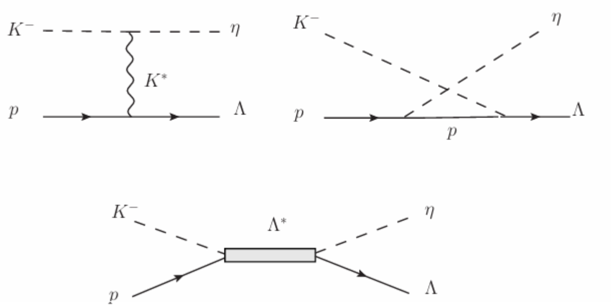
Bo-Chao Liu[1,2,*] and Ju-Jun Xie[3,2,†]

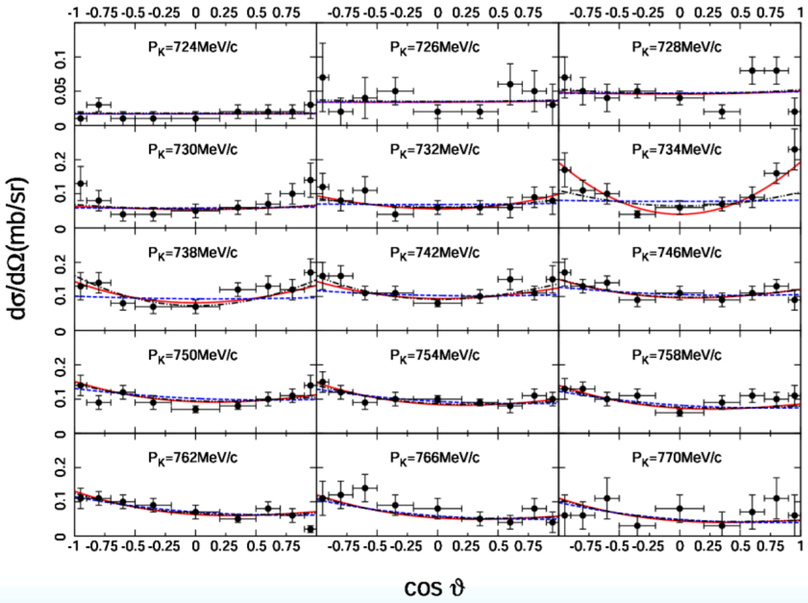
[1] *Department of Applied Physics, Xi'an Jiaotong University, Xi'an, Shanxi 710049, China*
[2] *Theoretical Physics Center for Science Facilities, Chinese Academy of Sciences, Beijing 100049, China*
[3] *Department of Physics, Zhengzhou University, Zhengzhou, Henan 450001, China*

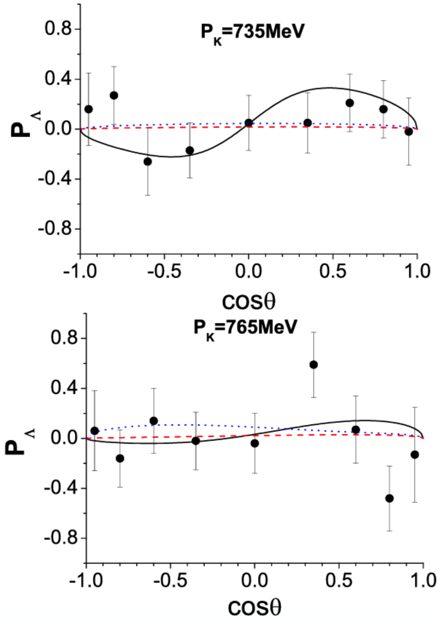
1. 树图阶的分波分析

B. C. Liu and J. J. Xie, Phys. Rev. C 85, 038201 (2012); Phys. Rev. C 86, 055202 (2012)

亮点：利用同位旋筛子细致研究Λ重子，找到一个极窄的Λ(1670)







Λ(1670)作为|[ud]{ss}¯ s>态给出了其主要的ηΛ衰变模式的自然解释，由于其非常小的相空间，导致其具有非常窄的宽度，同时还有一个D波衰变。

K介子束流理论研究

$\bar{K}N \to \eta\Lambda$

1. 树图阶的分波分析

Li-Ye Xiao, Xian-Hui Zhong,Phys.Rev.C 88 (2013) 6, 065201

$$\begin{pmatrix} |\Lambda(1800)\frac{1}{2}^-\rangle \\ |\Lambda(1670)\frac{1}{2}^-\rangle \\ |\Lambda(1405)\frac{1}{2}^-\rangle \end{pmatrix} = U \begin{pmatrix} |70,^2 1\rangle \\ |70,^2 8\rangle \\ |70,^4 8\rangle \end{pmatrix}, \qquad (20$$

with

$$U = \begin{pmatrix} c_{12}c_{13} & s_{12}c_{13} & s_{13} \\ -s_{12}c_{23} - c_{12}s_{23}s_{13} & c_{12}c_{23} - s_{12}s_{23}s_{13} & s_{23}c_{13} \\ s_{12}s_{23} - c_{12}c_{23}s_{13} & -c_{12}s_{23} - s_{12}c_{23}s_{13} & c_{23}c_{13} \end{pmatrix},$$

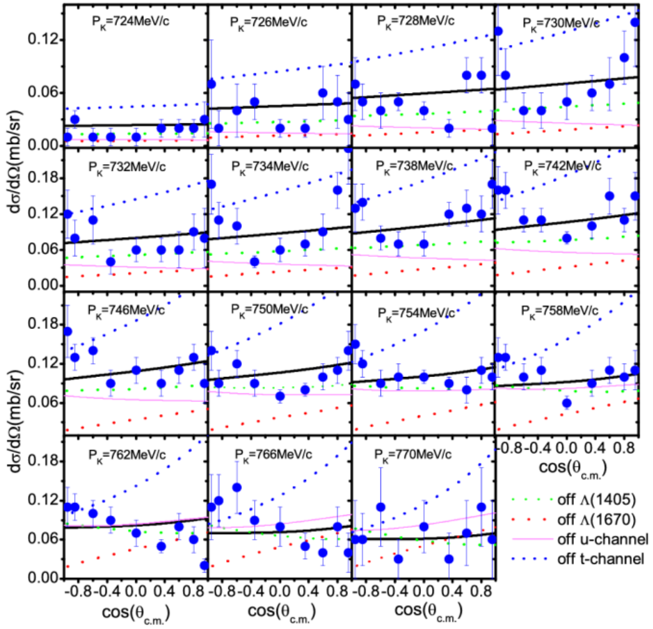
$$\begin{pmatrix} |\Lambda(1800)\frac{1}{2}^-\rangle \\ |\Lambda(1670)\frac{1}{2}^-\rangle \\ |\Lambda(1405)\frac{1}{2}^-\rangle \end{pmatrix} = \begin{pmatrix} 0.17 & 0.62 & 0.77 \\ 0.39 & -0.76 & 0.53 \\ 0.90 & 0.21 & -0.37 \end{pmatrix} \begin{pmatrix} |70,^2 1\rangle \\ |70,^2 8\rangle \\ |70,^4 8\rangle \end{pmatrix}$$

$$\begin{pmatrix} |\Lambda(1520)\frac{3}{2}^-\rangle \\ |\Lambda(1690)\frac{3}{2}^-\rangle \\ |\Lambda\frac{3}{2}^-\rangle_3 \end{pmatrix} = \begin{pmatrix} 0.94 & 0.34 & 0.09 \\ 0.31 & -0.92 & 0.26 \\ 0.17 & -0.21 & -0.96 \end{pmatrix} \begin{pmatrix} |70,^2 1\rangle \\ |70,^2 8\rangle \\ |70,^4 8\rangle \end{pmatrix}$$

Low energy reaction $K^- p \to \Lambda\eta$ and the negative parity Λ resonances

Li-Ye Xiao and Xian-Hui Zhong *

亮点：结合夸克模型来进行振幅分析



K-p→Λη过程的数据显示，在ηΛ阈值附近的一个窄能量区域存在一个碗状结构，表明在那里存在强D波贡献。然而，Λ(1690)D03对K-P→Λη过程的贡献太小，无法形成碗状结构。构型混合效应也无法解释。

$$|\Lambda(1405)\rangle = a_1|70,^2 1\rangle_S + b_1|70,^2 8\rangle_S + c_1|70,^4 8\rangle_S,$$
$$|\Lambda(1670)\rangle = a_2|70,^2 1\rangle_S + b_2|70,^2 8\rangle_S + c_2|70,^4 8\rangle_S,$$
$$|\Lambda(1520)\rangle = a_3|70,^2 1\rangle_D + b_3|70,^2 8\rangle_D + c_3|70,^4 8\rangle_D,$$
$$|\Lambda(1690)\rangle = a_4|70,^2 1\rangle_D + b_4|70,^2 8\rangle_D + c_4|70,^4 8\rangle_D,$$

K介子束流理论研究

$$K^- p \;\to \overline{K}^0 n, \pi^0\Lambda, \pi^0\Sigma^0$$

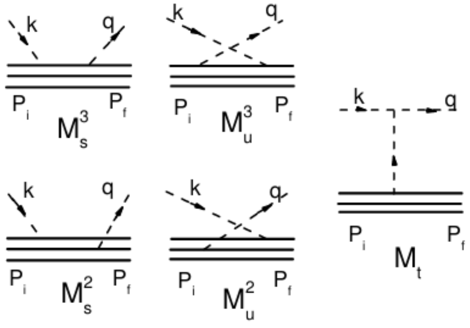
Low energy reactions $K^- p \to \Sigma^0\pi^0$, $\Lambda\pi^0$, $\bar{K}^0 n$ and the strangeness $S = -1$ hyperons

Xian-Hui Zhong[1,3 *] and Qiang Zhao[2,3 †]

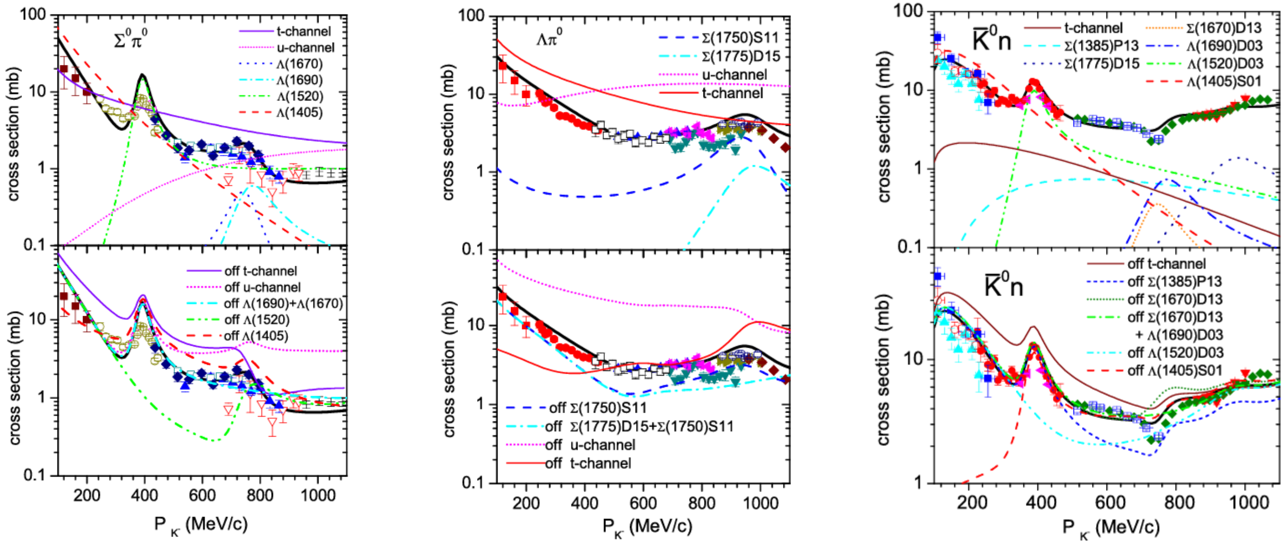
1. 树图阶的分波分析

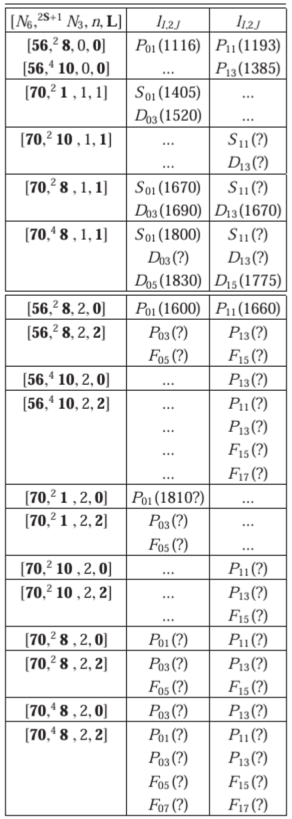
Xian-Hui Zhong, Qiang Zhao, Phys.Rev.C 88 (2013) 015208

亮点：结合夸克模型来进行振幅分析，在$\pi^0\Sigma^0$只有$\boldsymbol{\Lambda}$，在$\pi^0\Lambda$只有$\boldsymbol{\Sigma}$，在$\overline{K}^0 n$有$\boldsymbol{\Lambda}$和$\boldsymbol{\Sigma}$



$$H_m = \frac{1}{f_m}\bar{\psi}_j\gamma_\mu^j\gamma_5^j\psi_j\vec{\tau}\cdot\partial^\mu\vec{\phi}_m,$$

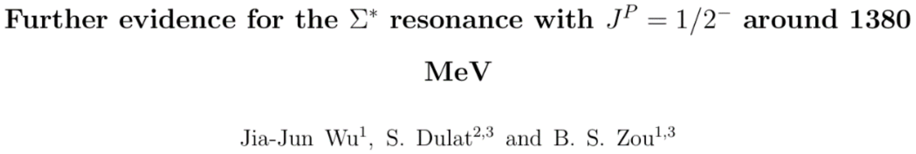




$[N_6, {}^{2\mathbf{S}+1}N_3, n, \mathbf{L}]$	$l_{I,2J}$	$l_{I,2J}$
$[\mathbf{56}, {}^2\mathbf{8}, 0, \mathbf{0}]$	$P_{01}(1116)$	$P_{11}(1193)$
$[\mathbf{56}, {}^4\mathbf{10}, 0, \mathbf{0}]$	...	$P_{13}(1385)$
$[\mathbf{70}, {}^2\mathbf{1}, 1, 1]$	$S_{01}(1405)$ $D_{03}(1520)$	... ...
$[\mathbf{70}, {}^2\mathbf{10}, 1, \mathbf{1}]$	... ...	$S_{11}(?)$ $D_{13}(?)$
$[\mathbf{70}, {}^2\mathbf{8}, 1, \mathbf{1}]$	$S_{01}(1670)$ $D_{03}(1690)$	$S_{11}(?)$ $D_{13}(1670)$
$[\mathbf{70}, {}^4\mathbf{8}, 1, \mathbf{1}]$	$S_{01}(1800)$ $D_{03}(?)$ $D_{05}(1830)$	$S_{11}(?)$ $D_{13}(?)$ $D_{15}(1775)$
$[\mathbf{56}, {}^2\mathbf{8}, 2, \mathbf{0}]$	$P_{01}(1600)$	$P_{11}(1660)$
$[\mathbf{56}, {}^2\mathbf{8}, 2, \mathbf{2}]$	$P_{03}(?)$ $F_{05}(?)$	$P_{13}(?)$ $F_{15}(?)$
$[\mathbf{56}, {}^4\mathbf{10}, 2, \mathbf{0}]$	...	$P_{13}(?)$
$[\mathbf{56}, {}^4\mathbf{10}, 2, \mathbf{2}]$	... ...	$P_{11}(?)$ $P_{13}(?)$ $F_{15}(?)$ $F_{17}(?)$
$[\mathbf{70}, {}^2\mathbf{1}, 2, \mathbf{0}]$	$P_{01}(1810?)$	...
$[\mathbf{70}, {}^2\mathbf{1}, 2, \mathbf{2}]$	$P_{03}(?)$ $F_{05}(?)$	... ...
$[\mathbf{70}, {}^2\mathbf{10}, 2, \mathbf{0}]$	...	$P_{11}(?)$
$[\mathbf{70}, {}^2\mathbf{10}, 2, \mathbf{2}]$	... ...	$P_{13}(?)$ $F_{15}(?)$
$[\mathbf{70}, {}^2\mathbf{8}, 2, \mathbf{0}]$	$P_{01}(?)$	$P_{11}(?)$
$[\mathbf{70}, {}^2\mathbf{8}, 2, \mathbf{2}]$	$P_{03}(?)$ $F_{05}(?)$	$P_{13}(?)$ $F_{15}(?)$
$[\mathbf{70}, {}^4\mathbf{8}, 2, \mathbf{0}]$	$P_{03}(?)$	$P_{13}(?)$
$[\mathbf{70}, {}^4\mathbf{8}, 2, \mathbf{2}]$	$P_{01}(?)$ $P_{03}(?)$ $F_{05}(?)$ $F_{07}(?)$	$P_{11}(?)$ $P_{13}(?)$ $F_{15}(?)$ $F_{17}(?)$

K介子束流理论研究

$K^- p \to \Lambda(1520) \to \Lambda\pi\pi$



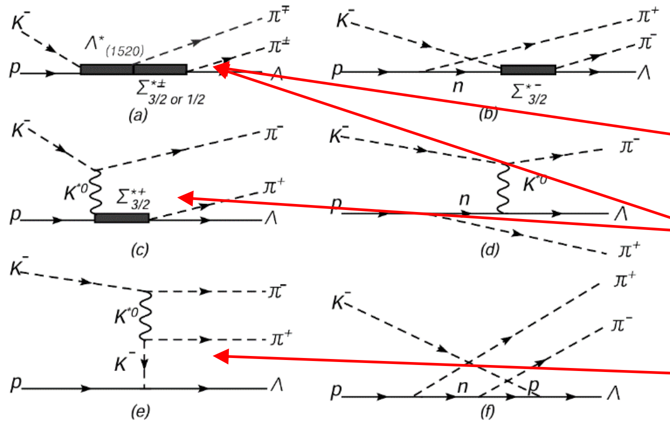
Further evidence for the Σ^* resonance with $J^P = 1/2^-$ around 1380 MeV

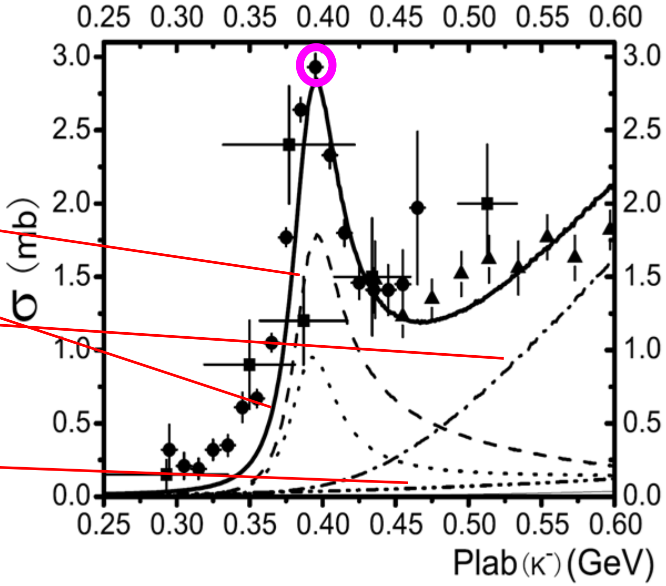
Jia-Jun Wu[1], S. Dulat[2,3] and B. S. Zou[1,3]

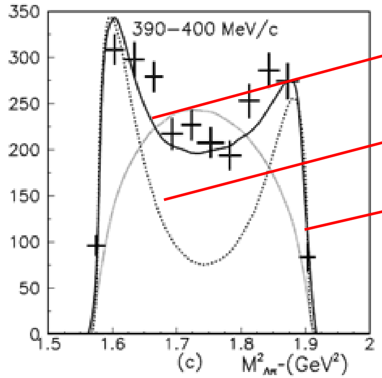
1. 树图阶的分波分析

亮点：三体末态分析，发现Σ(1380)1/2 −

Jia-Jun Wu,S. Dulat,B.S. Zou, Phys.Rev.C 81 (2010) 045210



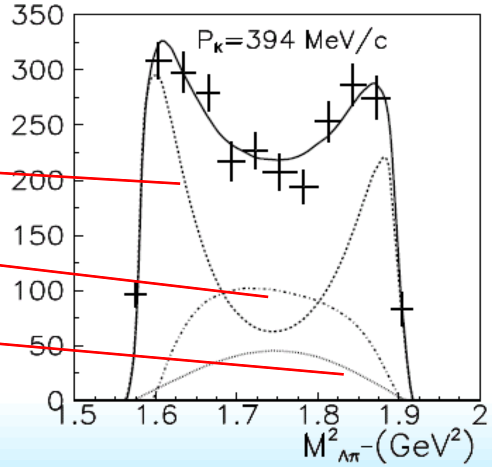




59% Σ*(3/2⁺)+ 41% Σ*(1/2⁻)

100% Σ*(3/2⁺)

Phase space



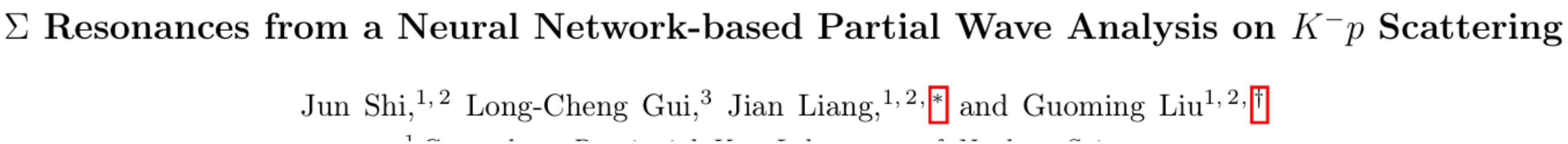
59% Σ*(3/2⁺)

Interference

12.5% Σ*(1/2⁻)

K介子束流理论研究

$\bar{K}N \to \pi\Lambda$



Σ Resonances from a Neural Network-based Partial Wave Analysis on K^-p Scattering

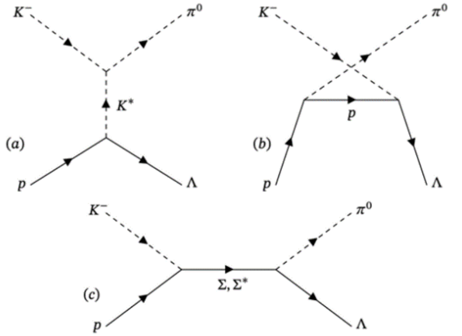
Jun Shi,[1,2] Long-Cheng Gui,[3] Jian Liang,[1,2,*] and Guoming Liu[1,2,†]

1. 树图阶的分波分析

Jun Shi，Long-Cheng Gui,Jian Liang，and Guoming Liu， 2305.01852 [hep-ph]

亮点：利用神经网络来进行分波分析

a. 生产训练集

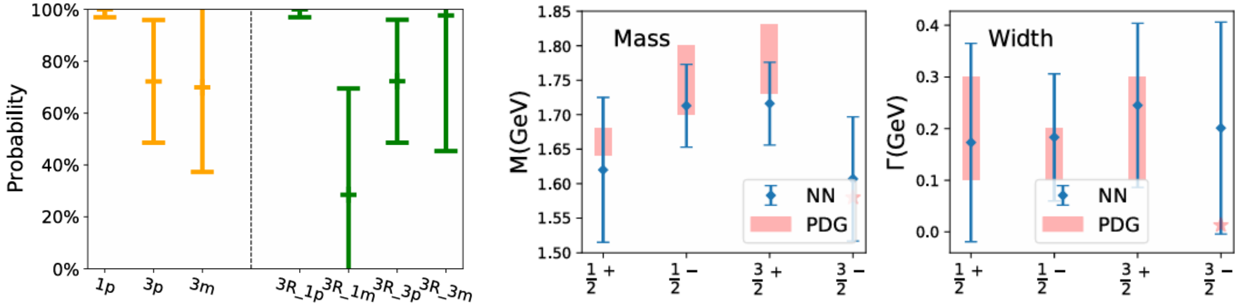
参数 →  → 数据

b. 训练神经网络

赝数据 → 神经网络 → 粒子参数

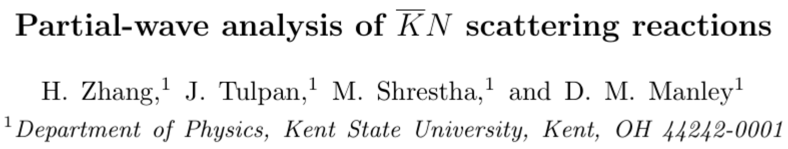
c. 利用神经网络处理实验数据

实验数据 → 神经网络 → 粒子参数



实现：粒子的分类和粒子参数的回归

K介子束流理论研究


Partial-wave analysis of $\overline{K}N$ scattering reactions

H. Zhang,[1] J. Tulpan,[1] M. Shrestha,[1] and D. M. Manley[1]

[1] *Department of Physics, Kent State University, Kent, OH 44242-0001*

$\overline{K}N$散射

2. 耦合道分波分析

Zhang,J. Tulpan,M. Shrestha,D.M. Manley，Phys.Rev.C 88 (2013) 3, 035204

亮点：单能量点分析，满足幺正性的动力学矩阵拟合方式。

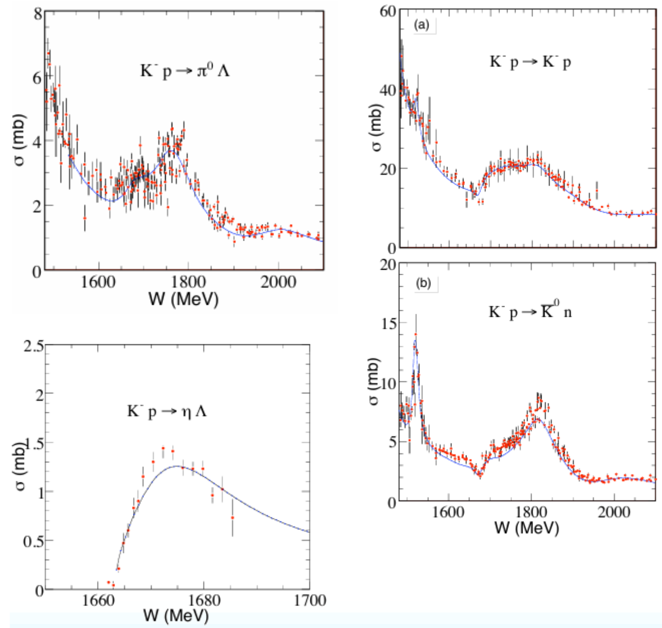
$$\frac{d\sigma}{d\Omega} = \lambda^2(|f|^2 + |g|^2) ,$$

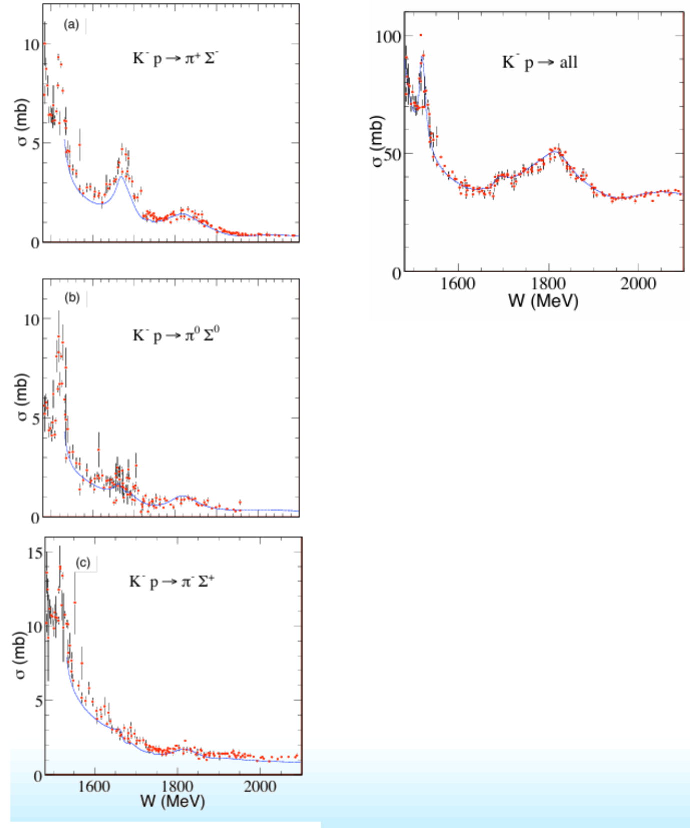
spin-non-flip and
spin-flip amplitudes

$$P\frac{d\sigma}{d\Omega} = 2\lambda^2 \mathrm{Im}(fg^*) ,$$

$$f(W,\theta) = \sum_{l=0}^{\infty}[(l+1)T_{l+} + lT_{l-}]P_l(\cos\theta) , \qquad g(W,\theta) = \sum_{l=1}^{\infty}[T_{l+} - T_{l-}]P_l^1(\cos\theta) ,$$

$$T(W) = T(W_0) + T'(W_0)(W - W_0)$$





K介子束流理论研究

$\bar{K}N$散射

2.耦合道分波分析

M. Matveev，A.V. Sarantsev，V.A. Nikonov，A.V. Anisovich，U. Thoma
Eur.Phys.J.A 55 (2019) 10, 179

第一步，用BW形式进行预拟合

$$A(s)=\sum_{\beta}\frac{g^{\beta}_{in}g^{\beta}_{out}}{M^2_{\beta}-s-iM_{\beta}\Gamma^{\beta}_{tot}}$$

第二步，用K矩阵或者D矩阵形式进行最终拟合

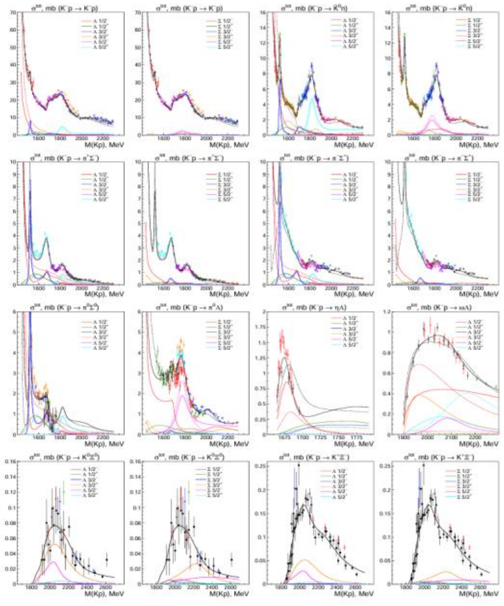
$$A_{ij}(s)=K_{im}(I-i\hat{\rho}\hat{K})^{-1}_{mj}\,,\qquad K_{ij}=\sum_{\beta}\frac{g^{\beta}_i g^{\beta}_j}{M^2_{\beta}-s}+f_{ij}$$

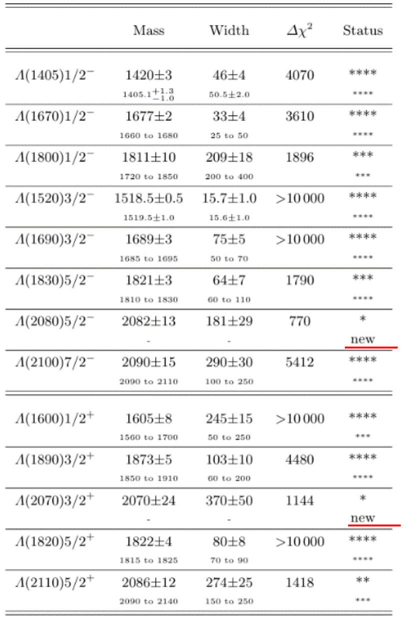
$$A_{ij}(s)=K_{im}(I-i\hat{\rho}\hat{K})^{-1}_{mk}(i\hat{\rho}\hat{D})_{kj}+D_{ij}\qquad D_{ij}=\sum_{\beta}\frac{g^{\beta}_i G^{\beta}_j}{M^2_{\beta}-s}+F_{ij}$$

Hyperon I: Partial wave amplitudes for K^-p scattering

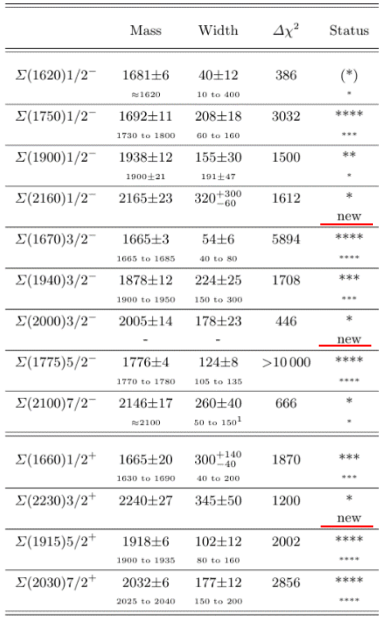
M. Matveev[1,2], A.V. Sarantsev[1,2], V.A. Nikonov[1,2], A.V. Anisovich[1,2], U. Thoma[1], and E. Klempt[1a]
[1]Helmholtz–Institut für Strahlen– und Kernphysik, Universität Bonn, 53115 Bonn, Germany
[2]National Research Centre “Kurchatov Institute”, Petersburg Nuclear Physics Institute, Gatchina, 188300 Russia

亮点：BnGa partial wave analysis，满足幺正性的K矩阵拟合方式。



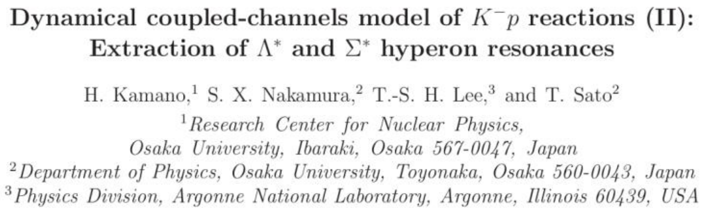


	Mass	Width	$\Delta\chi^2$	Status
$\Lambda(1405)1/2^-$	1420±3 $1405.1^{+1.3}_{-1.0}$	46±4 50.5±2.0	4070	**** ****
$\Lambda(1670)1/2^-$	1677±2 1660 to 1680	33±4 25 to 50	3610	**** ****
$\Lambda(1800)1/2^-$	1811±10 1720 to 1850	209±18 200 to 400	1896	*** ***
$\Lambda(1520)3/2^-$	1518.5±0.5 1519.5±1.0	15.7±1.0 15.6±1.0	>10 000	**** ****
$\Lambda(1690)3/2^-$	1689±3 1685 to 1695	75±5 50 to 70	>10 000	**** ****
$\Lambda(1830)5/2^-$	1821±3 1810 to 1830	64±7 60 to 110	1790	*** ****
$\Lambda(2080)5/2^-$	2082±13 -	181±29 -	770	* new
$\Lambda(2100)7/2^-$	2090±15 2090 to 2110	290±30 100 to 250	5412	**** ****
$\Lambda(1600)1/2^+$	1605±8 1560 to 1700	245±15 50 to 250	>10 000	**** ***
$\Lambda(1890)3/2^+$	1873±5 1850 to 1910	103±10 60 to 200	4480	**** ****
$\Lambda(2070)3/2^+$	2070±24 -	370±50 -	1144	* new
$\Lambda(1820)5/2^+$	1822±4 1815 to 1825	80±8 70 to 90	>10 000	**** ****
$\Lambda(2110)5/2^+$	2086±12 2090 to 2140	274±25 150 to 250	1418	** ***



	Mass	Width	$\Delta\chi^2$	Status
$\Sigma(1620)1/2^-$	1681±6 ≈1620	40±12 10 to 400	386	(*) *
$\Sigma(1750)1/2^-$	1692±11 1730 to 1800	208±18 60 to 160	3032	**** ***
$\Sigma(1900)1/2^-$	1938±12 1900±21	155±30 191±47	1500	** *
$\Sigma(2160)1/2^-$	2165±23	320^{+300}_{-60}	1612	* new
$\Sigma(1670)3/2^-$	1665±3 1665 to 1685	54±6 40 to 80	5894	**** ****
$\Sigma(1940)3/2^-$	1878±12 1900 to 1950	224±25 150 to 300	1708	*** ***
$\Sigma(2000)3/2^-$	2005±14 -	178±23 -	446	* new
$\Sigma(1775)5/2^-$	1776±4 1770 to 1780	124±8 105 to 135	>10 000	**** ****
$\Sigma(2100)7/2^-$	2146±17 ≈2100	260±40 50 to 150[1]	666	* *
$\Sigma(1660)1/2^+$	1665±20 1630 to 1690	300^{+140}_{-40} 40 to 200	1870	*** ***
$\Sigma(2230)3/2^+$	2240±27	345±50	1200	* new
$\Sigma(1915)5/2^+$	1918±6 1900 to 1935	102±12 80 to 160	2002	**** ****
$\Sigma(2030)7/2^+$	2032±6 2025 to 2040	177±12 150 to 200	2856	**** ****

K介子束流理论研究



Dynamical coupled-channels model of K^-p reactions (II): Extraction of Λ^* and Σ^* hyperon resonances

H. Kamano,[1] S. X. Nakamura,[2] T.-S. H. Lee,[3] and T. Sato[2]

[1] *Research Center for Nuclear Physics, Osaka University, Ibaraki, Osaka 567-0047, Japan*

[2] *Department of Physics, Osaka University, Toyonaka, Osaka 560-0043, Japan*

[3] *Physics Division, Argonne National Laboratory, Argonne, Illinois 60439, USA*

$\bar{K}N$散射

2. 耦合道分波分析

H. Kamano, S. X. Nakamura, T.-S. H. Lee and T. Sato, PRC 90 (2014) 065204， 92 (2015) 025205

亮点：Argonn-Osaka PWA，满足幺正性的动力学矩阵拟合方式。

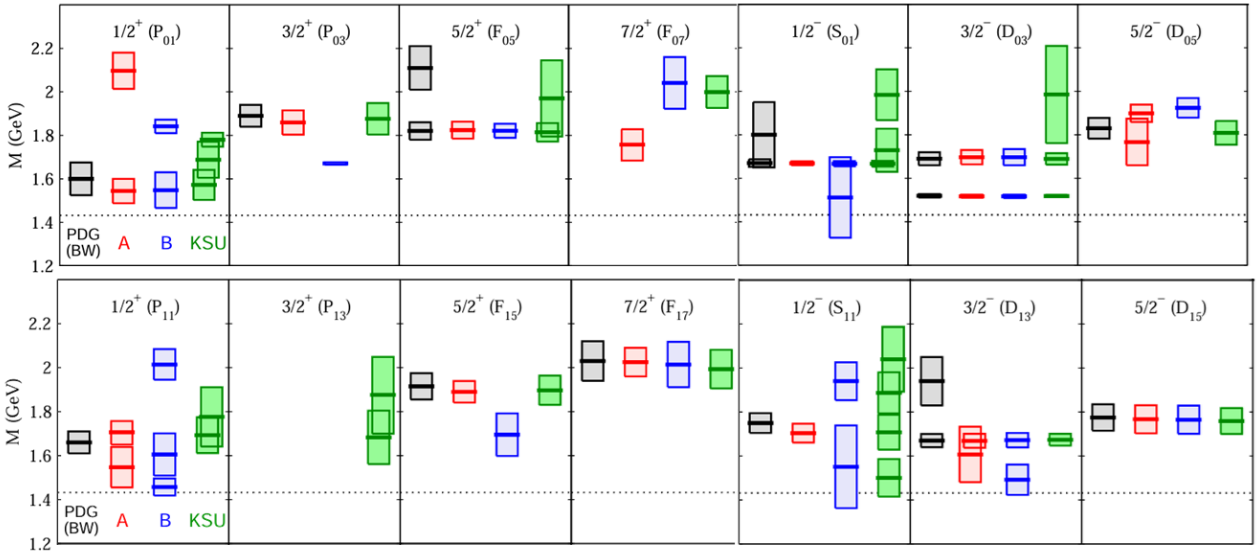
$$A_{ij}(s) = K_{im}(I - i\hat{\rho}\hat{K})^{-1}_{mj}\,, \qquad K_{ij} = \sum_{\beta} \frac{g_i^{\beta} g_j^{\beta}}{M_{\beta}^2 - s} + f_{ij}$$

$$T_{\beta,\alpha}(p_\beta, p_\alpha; W) = V_{\beta,\alpha}(p_\beta, p_\alpha; W) + \sum_{\delta} \int p^2 dp V_{\beta,\delta}(p_\beta, p; W) G_\delta(p; W) T_{\delta,\alpha}(p, p_\alpha; W),$$

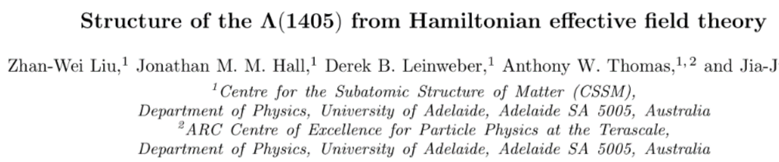
with

$$V_{\beta,\alpha}(p_\beta, p_\alpha; W) = v_{\beta,\alpha}(p_\beta, p_\alpha) + \sum_{Y^*} \frac{\Gamma^{\dagger}_{Y^*,\beta}(p_\beta)\Gamma_{Y^*,\alpha}(p_\alpha)}{W - M^0_{Y^*}},$$

一个积分方程的耦合道模型，更加复杂，但是考虑了势能的积分效应



K介子束流理论研究



Structure of the Λ(1405) from Hamiltonian effective field theory

Zhan-Wei Liu,[1] Jonathan M. M. Hall,[1] Derek B. Leinweber,[1] Anthony W. Thomas,[1,2] and Jia-Jun Wu[1]

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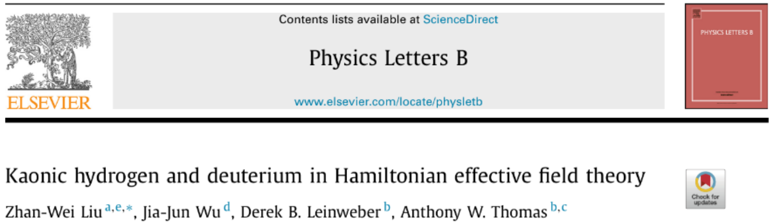
Department of Physics, University of Adelaide, Adelaide SA 5005, Australia
[2]ARC Centre of Excellence for Particle Physics at the Terascale,
Department of Physics, University of Adelaide, Adelaide SA 5005, Australia



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Kaonic hydrogen and deuterium in Hamiltonian effective field theory

Zhan-Wei Liu[a,e,*], Jia-Jun Wu[d], Derek B. Leinweber[b], Anthony W. Thomas[b,c]

$\bar{K}N$散射

2. 耦合道分波分析

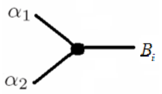
Zhan-Wei Liu, Jonathan M.M. Hall, Derek B. Leinweber, Anthony W. Thomas, Jia-Jun Wu, *Phys. Rev. D* 95 (2017) 1, 014506,
Phys. Lett. B 808 (2020) 135652

亮点：满足幺正性的动力学耦合道方法，和Argonne类似，亮点是结合格点计算。

$$H = H_0 + H_I$$

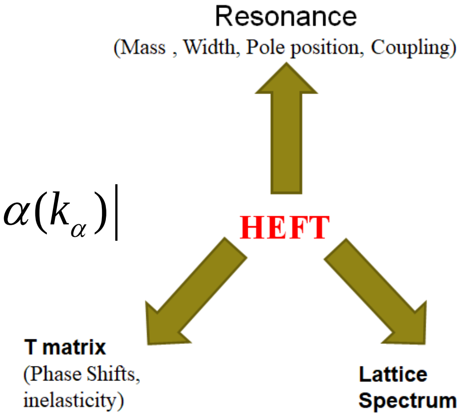
$$H_0=\sum_{i=1,n}|B_i\rangle m_i\langle B_i|+\sum_{\alpha}|\alpha(k_\alpha)\rangle\left[\sqrt{m_{\alpha1}^2+k_\alpha^2}+\sqrt{m_{\alpha2}^2+k_\alpha^2}\right]\langle\alpha(k_\alpha)|$$

$$H_I = \hat{g} + \hat{v}$$



$$\hat{g}=\sum_{\alpha}\sum_{i=1,n}\left[|\alpha(k_\alpha)\rangle g_{i,\alpha}^{+}\langle B_i|+|B_i\rangle g_{i,\alpha}\langle\alpha(k_\alpha)|\right]$$

$$\hat{v}=\sum_{\alpha,\beta}|\alpha(k_\alpha)\rangle v_{\alpha,\beta}\langle\beta(k_\beta)|$$

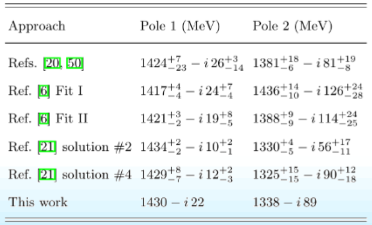


Resonance
(Mass , Width, Pole position, Coupling)

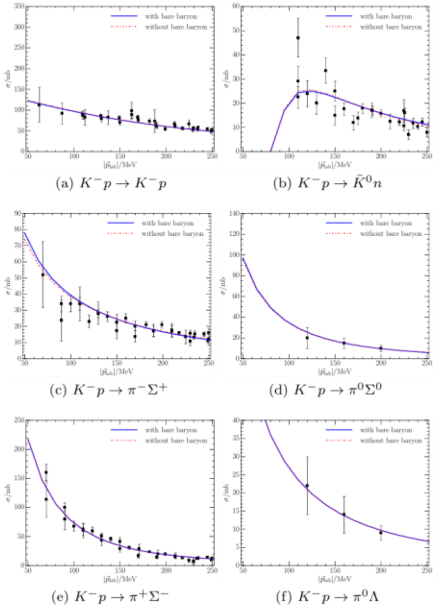
HEFT

T matrix
(Phase Shifts, inelasticity)

Lattice Spectrum



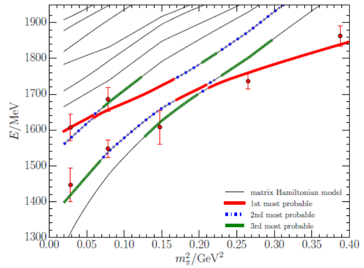
Approach	Pole 1 (MeV)	Pole 2 (MeV)
Refs. [20, 50]	$1424^{+7}_{-23}-i\,26^{+3}_{-14}$	$1381^{+18}_{-6}-i\,81^{+19}_{-8}$
Ref. [6] Fit I	$1417^{+4}_{-4}-i\,24^{+7}_{-4}$	$1436^{+14}_{-10}-i\,126^{+24}_{-28}$
Ref. [6] Fit II	$1421^{+3}_{-2}-i\,19^{+8}_{-5}$	$1388^{+9}_{-9}-i\,114^{+24}_{-25}$
Ref. [21] solution #2	$1434^{+2}_{-2}-i\,10^{+2}_{-1}$	$1330^{+4}_{-5}-i\,56^{+17}_{-11}$
Ref. [21] solution #4	$1429^{+8}_{-7}-i\,12^{+2}_{-3}$	$1325^{+15}_{-15}-i\,90^{+12}_{-18}$
This work	$1430-i\,22$	$1338-i\,89$

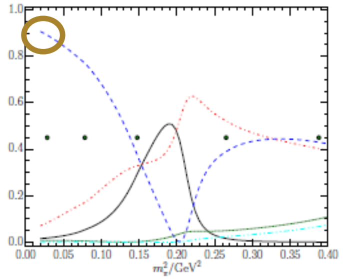


(a) $K^-p\to K^-p$ (b) $K^-p\to\bar{K}^0n$

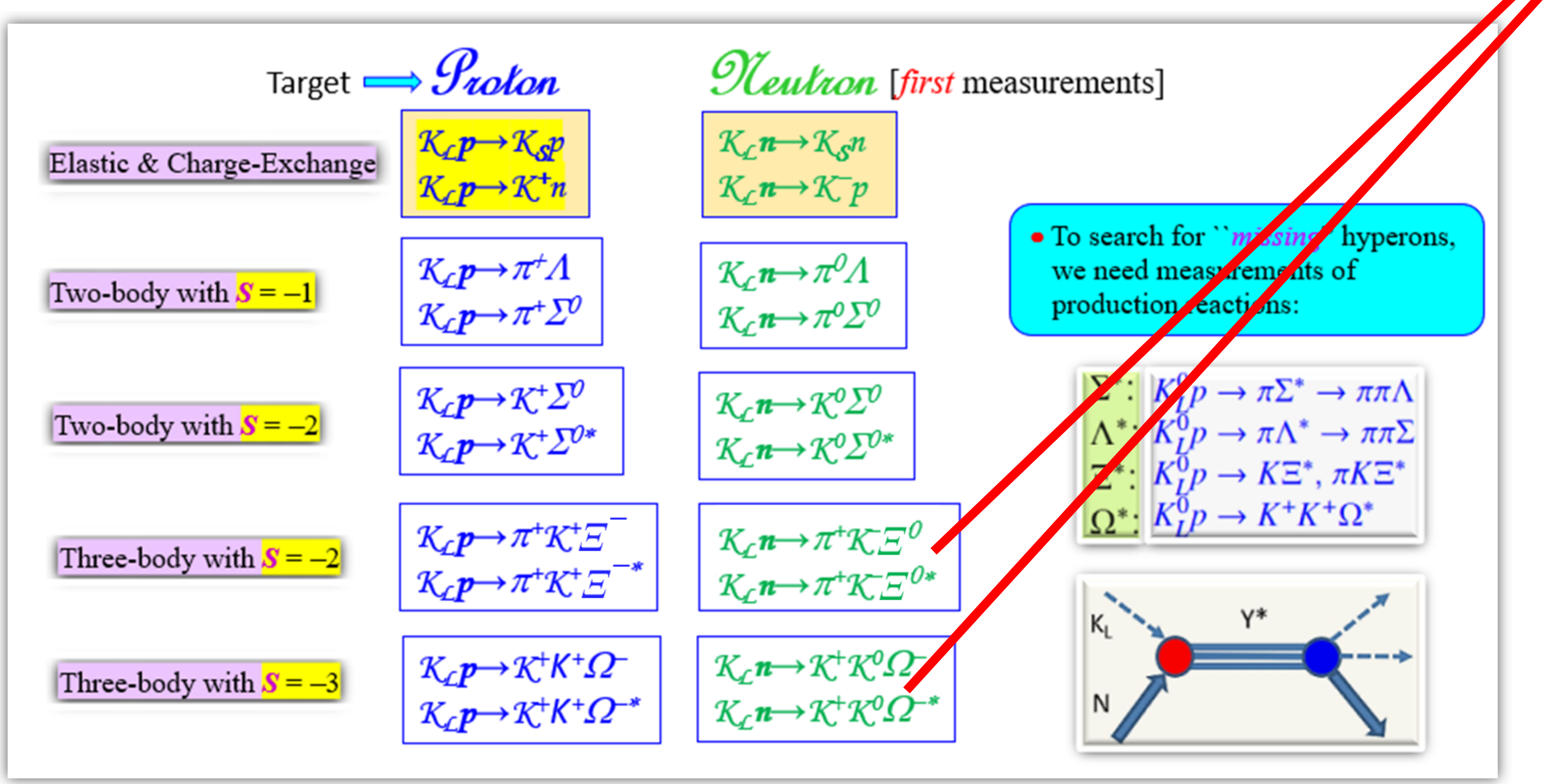
(c) $K^-p\to\pi^-\Sigma^+$ (d) $K^-p\to\pi^0\Sigma^0$

(e) $K^-p\to\pi^+\Sigma^-$ (f) $K^-p\to\pi^0\Lambda$





K介子束流理论研究



Target ⟹ Proton　Neutron [*first* measurements]

	Proton	Neutron
Elastic & Charge-Exchange	$K_L p \to K_S p$ $K_L p \to K^+ n$	$K_L n \to K_S n$ $K_L n \to K^- p$
Two-body with $S = -1$	$K_L p \to \pi^+ \Lambda$ $K_L p \to \pi^+ \Sigma^0$	$K_L n \to \pi^0 \Lambda$ $K_L n \to \pi^0 \Sigma^0$
Two-body with $S = -2$	$K_L p \to K^+ \Sigma^0$ $K_L p \to K^+ \Sigma^{0*}$	$K_L n \to K^0 \Sigma^0$ $K_L n \to K^0 \Sigma^{0*}$
Three-body with $S = -2$	$K_L p \to \pi^+ K^+ \Xi^-$ $K_L p \to \pi^+ K^+ \Xi^{-*}$	$K_L n \to \pi^+ K^- \Xi^0$ $K_L n \to \pi^+ K^- \Xi^{0*}$
Three-body with $S = -3$	$K_L p \to K^+ K^+ \Omega^-$ $K_L p \to K^+ K^+ \Omega^{-*}$	$K_L n \to K^+ K^0 \Omega^-$ $K_L n \to K^+ K^0 \Omega^{-*}$

- To search for "*missing*" hyperons, we need measurements of production reactions:

Σ^*: $K_L^0 p \to \pi \Sigma^* \to \pi\pi\Lambda$

Λ^*: $K_L^0 p \to \pi \Lambda^* \to \pi\pi\Sigma$

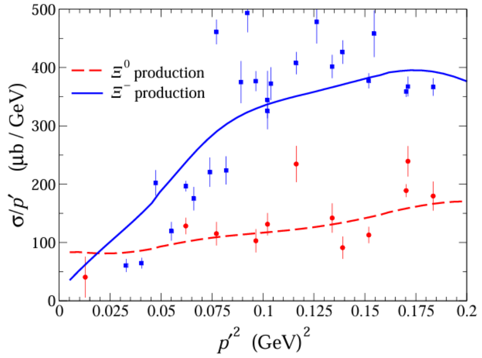
Ξ^*: $K_L^0 p \to K\Xi^*, \pi K \Xi^*$

Ω^*: $K_L^0 p \to K^+ K^+ \Omega^*$

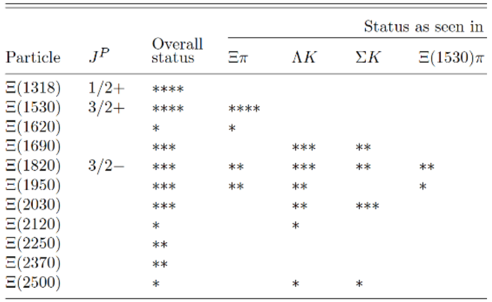
几乎是空白！

$\bar{K} + N \to K + \Xi$ reaction and $S = -1$ hyperon resonances

Benjamin C. Jackson,[1] Yongseok Oh,[2,3,*] H. Haberzettl,[4,†] and K. Nakayama[1,5,‡]



需要比较高的K束流能量，最好到4GeV，对应质心能量是2.94GeV，扣除末态K介子质量，可以研究2.5GeV一下的 Ξ重子 。



Particle	J^P	Overall status	Status as seen in			
			$\Xi\pi$	ΛK	ΣK	$\Xi(1530)\pi$
$\Xi(1318)$	$1/2+$	****				
$\Xi(1530)$	$3/2+$	****	****			
$\Xi(1620)$		*	*			
$\Xi(1690)$		***		***	**	
$\Xi(1820)$	$3/2-$	***	**	***	**	**
$\Xi(1950)$		***	**	**		*
$\Xi(2030)$		***		**	***	
$\Xi(2120)$		*		*		
$\Xi(2250)$		**				
$\Xi(2370)$		**				
$\Xi(2500)$		*		*	*	

小结

- $\overline{K}N$散射的实验的四个时期
- 多种不同方法的分波分析，方法不同，结果不尽相同，对于Λ,Σ重子态的研究方兴未艾，需要更多的实验数据。
- Ξ,Ω产生道的研究几乎是空白

谢谢