HHaS：Light-Hadron Physics & baryon study

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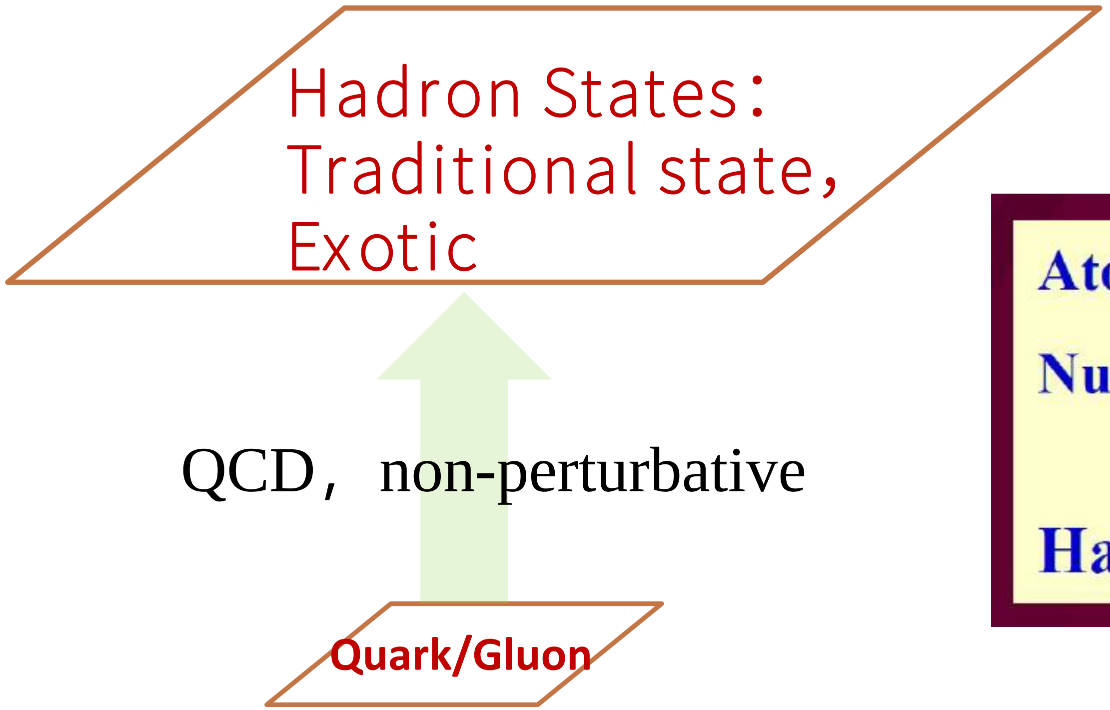
University of Chinese Academy of Sciences

Outline

- **Background**
- **p beam**
- **K beam for Ξ baryon**
- **Summary**

Background



Hadron spectroscopy

Hadron internal structure

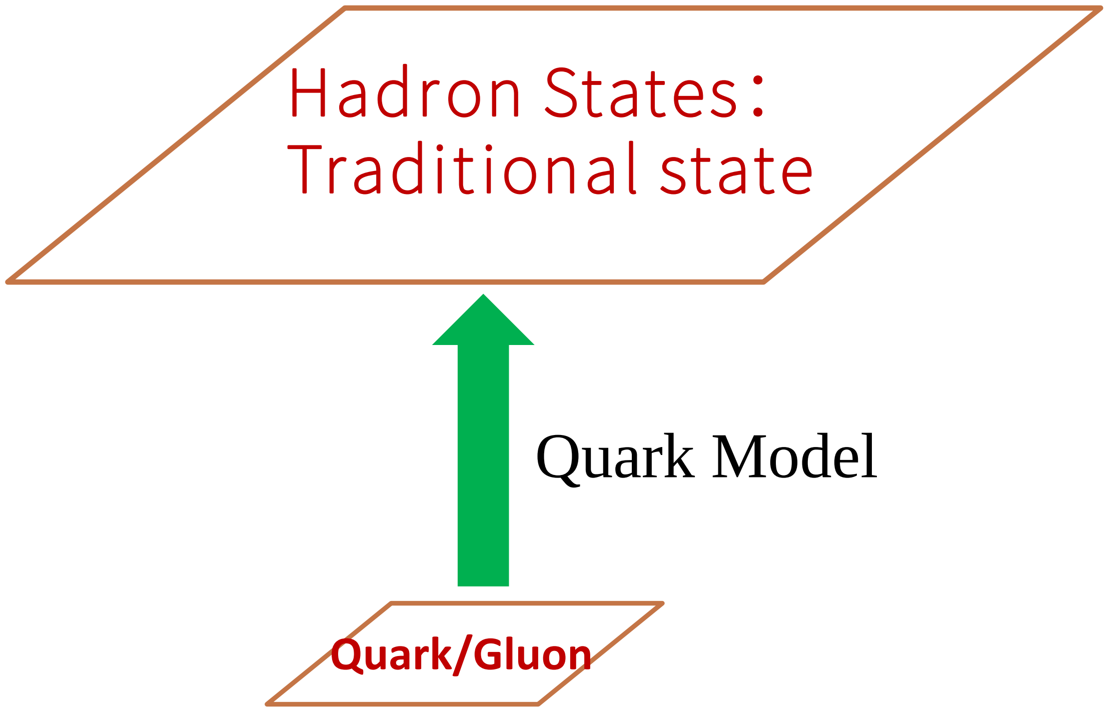
Atomic spectroscopy → Atomic Quantum Theory

Nuclear spectroscopy → Shell Model & Collective motion Model

Hadron spectroscopy → ?

From Prof. Bing-Song Zou

Background



Hadron spectroscopy

Hadron internal structure

Background

Hadron States:
Traditional state,
Exotic

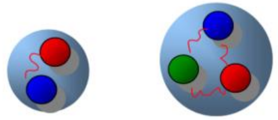
Quark Model ??

non-perturbative

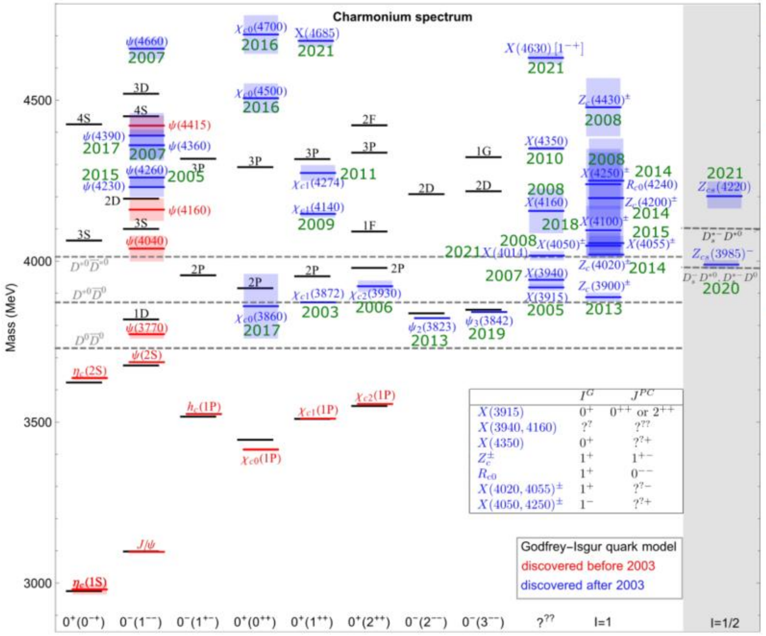
Quark/Gluon

Hadron spectroscopy
Hadron internal structure

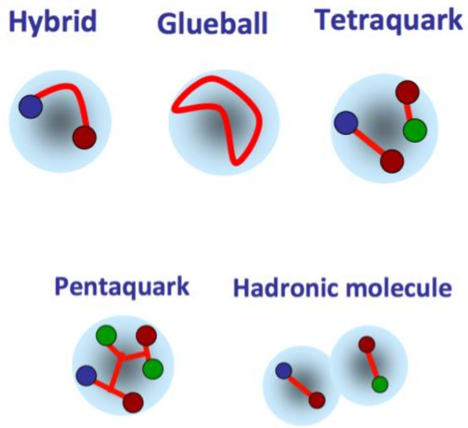
conventional hadron



(q q̄) (qqq)



Exotic



Background

Hadron States:
Traditional state,
Exotic

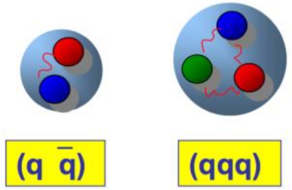
Quark Model ??

non-perturbative

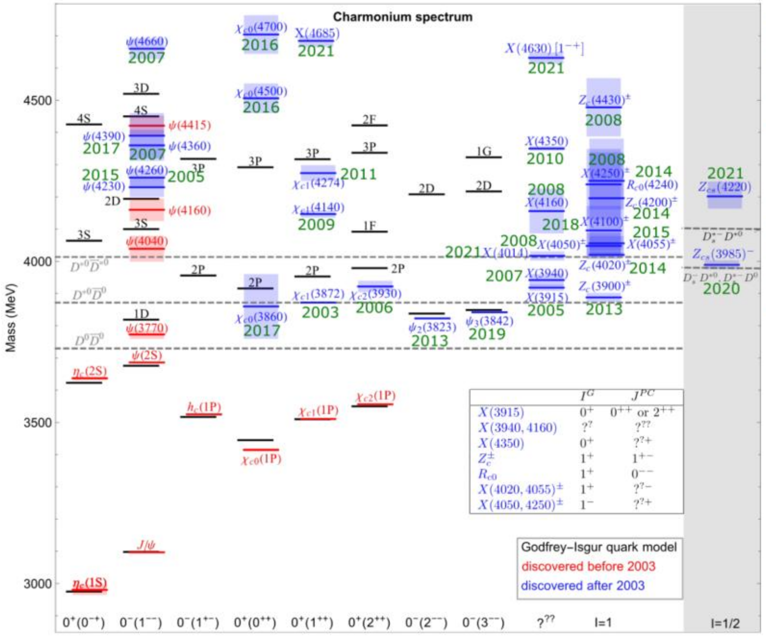
Quark/Gluon

UNQUENCHED quark model

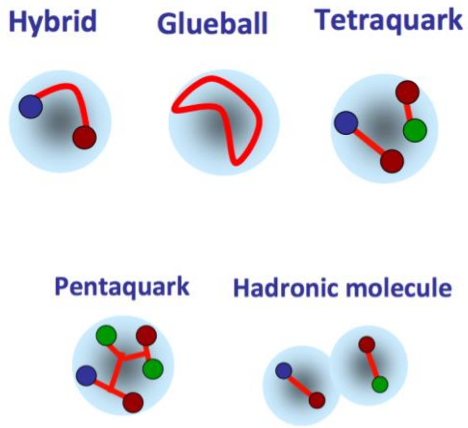
conventional hadron



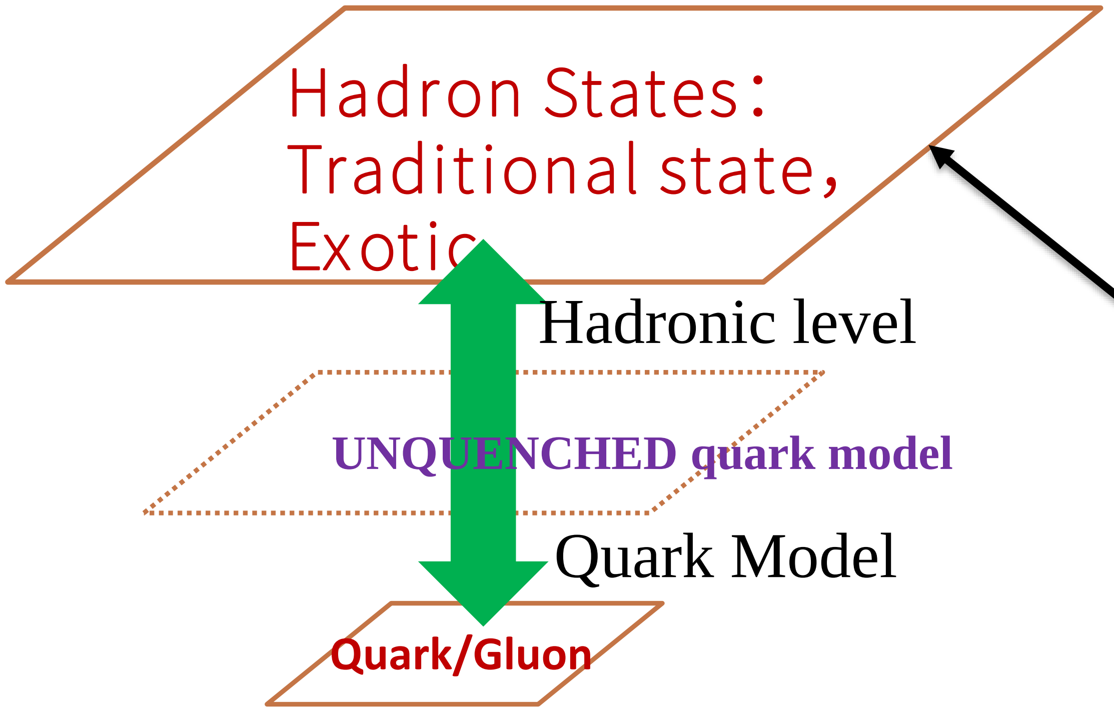
Hadron spectroscopy
Hadron internal structure



Exotic



Background



Hadron spectroscopy

Hadron internal structure

Experimental data input！！！
Decay and Scattering
Need hadron beam！！！

Proton beam and K beam

Background

- **The proton beam luminosity on the B-Ring is 1.8×10^{12} pps (fast extraction, FE) and 4.5×10^{11} pps (slow extraction, SE), with a maximum energy of 9.3 GeV.**
- **The center-of-mass energy for pp collisions is W = 4.3 GeV, which is sufficient to produce baryonic excitation states below 3 GeV. This is highly significant for studying the energy spectrum of light hadrons.**

反应道	阈值束流动能 (MeV)
$pp \to pp\pi^0$	280
$pp \to pp\pi^+\pi-$	600
$pp \to pp\eta$	1258
$pp \to pK^+\Lambda$	1580
$pp \to pp\eta\pi^0$	1616
$pp \to pp\omega$	1890
$pp \to pp\eta'$	2405
$pp \to ppK^+K^-$	2494
$pp \to pp\phi$	2592

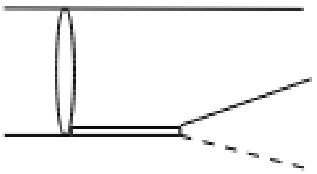
Production of exotic hadrons in pp and nuclear collisions*

Jinhui Chen[1,2] Feng-Kun Guo[3,4,5,6] Yu-Gang Ma[1,2] Cheng-Ping Shen[1,2] Qiye Shou[1,2] Qian Wang[7,8,6] Jia-Jun Wu[4] and Bing-Song Zou[9,3,5,6]

Nuclear Science and Techniques

Physics for Proton Beam

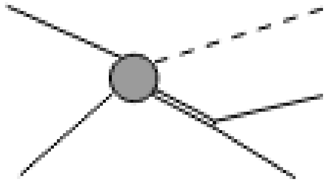
- **Excited Baryon!** N^*, Δ^* and Σ^*



(a)

1. Isospin filter, $pp \to n\Sigma^+K^+$, Σ^+K^+only for Δ^* J.J.Xie & B.S.Zou, PLB649 (2007) 405
2. Joint analysis of various process, rescattering effect for $pp \to pp\eta, p\Sigma K, p\Lambda K$ Q.F. Lyu, D.M. Li, CPC 39(2015) 113104
3. Search for pentaquark states, P_s state.

- **Double-baryon** Deuteron, d* (2380)

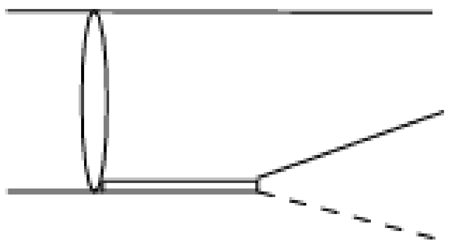


(b)

1. $pp \to X\pi\pi$, X has a baryon number of two
2. $pp \to D_{30}\pi^-\pi^- \to p\pi^+p\pi^+\pi^-\pi^-$, search d*(2380) with $I = I_z = 3$
3. $pd \to \mathrm{d}_\Lambda K$, Hyper deuteron

J.M.Richard, Q. Wang and Q.Zhao, PRC 91(2015)014003

Physics for Proton Beam



- **Excited Baryon ——— Δ^***

Isospin filter, $pp \to n\Delta^* \to n(p\pi^+/\Sigma^+K^+)$, only for Δ^*

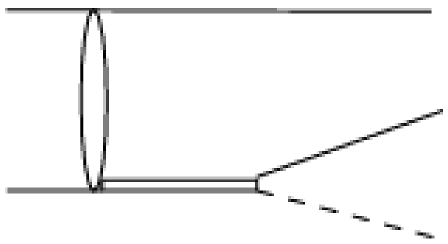
Particle	J^P	overall	$N\gamma$	$N\pi$	$\Delta\pi$	ΣK	$N\rho$	$\Delta\eta$
$\Delta(1232)$	$3/2^+$	****	****	****				
$\Delta(1600)$	$3/2^+$	****	****	***	****			
$\Delta(1620)$	$1/2^-$	****	****	****	****			
$\Delta(1700)$	$3/2^-$	****	****	****	****	*	*	
$\Delta(1750)$	$1/2^+$	*	*	*		*		
$\Delta(1900)$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

***** More/Less**

Δ^*, 12/10

J.J.Xie & B.S.Zou, PLB649 (2007) 405
Ju-Jun Xie, En Wang, Bing-Song Zou, PRC 90 (2014) 2, 025207
Xiao-Yun Wang, Xu Cao, Ju-Jun Xie, Xu-Rong Chen, PRC 92 (2015) 015202

Physics for Proton Beam



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$\Delta(1600)$	$3/2^+$	****	****	***	****			
$\Delta(1620)$	$1/2^-$	****	****	****	****			
$\Delta(1700)$	$3/2^-$	****	****	****	****	*	*	
$\Delta(1750)$	$1/2^+$	*	*	*		*		
$\Delta(1900)$	$1/2^-$	***	***	***	*	**	*	
$\Delta(1905)$	$5/2^+$	****	****	****	**	*	*	**
$\Delta(1910)$	$1/2^+$	****	***	****	**	**		*
$\Delta(1920)$	$3/2^+$	***	***	***	***	**		**
$\Delta(1930)$	$5/2^-$	***	*	***	*	*		
$\Delta(1940)$	$3/2^-$	**	*	**	*			*
$\Delta(1950)$	$7/2^+$	****	****	****	**	***		
$\Delta(2000)$	$5/2^+$	**	*	**	*		*	
$\Delta(2150)$	$1/2^-$	*		*				
$\Delta(2200)$	$7/2^-$	***	***	**	***	**		
$\Delta(2300)$	$9/2^+$	**		**				
$\Delta(2350)$	$5/2^-$	*		*				
$\Delta(2390)$	$7/2^+$	*		*				
$\Delta(2400)$	$9/2^-$	**	**	**				
$\Delta(2420)$	$11/2^+$	****	*	****				
$\Delta(2750)$	$13/2^-$	**		**				
$\Delta(2950)$	$15/2^+$	**		**				

***** More/Less**

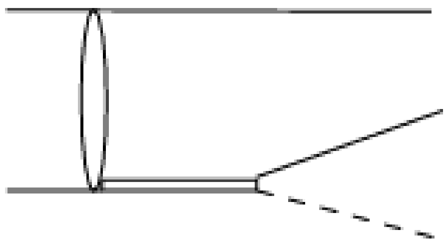
Δ^*, 12/10

Isospin filter, $pp \to n\Delta^* \to n(p\pi^+/\Sigma^+K^+)$, only for Δ^*

$K\Sigma(1190) \sim 1685$ MeV
$K\Sigma^*(1385) \sim 1880$ MeV
$K^*\Sigma(1190) \sim 2082$ MeV
$K^*\Sigma^*(1385) \sim 2277$ MeV

J.J.Xie & B.S.Zou, PLB649 (2007) 405
Ju-Jun Xie, En Wang, Bing-Song Zou, PRC 90 (2014) 2, 025207
Xiao-Yun Wang, Xu Cao, Ju-Jun Xie, Xu-Rong Chen, PRC 92 (2015) 015202

Physics for Proton Beam



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$\Delta(1600)$	$3/2^+$	****	****	***	****			
$\Delta(1620)$	$1/2^-$	****	****	****	****			
$\Delta(1700)$	$3/2^-$	****	****	****	****	*	*	
$\Delta(1750)$	$1/2^+$	*	*	*		*		
$\Delta(1900)$	$1/2^-$	***	***	***	*	**	*	
$\Delta(1905)$	$5/2^+$	****	****	****	**	*	*	**
$\Delta(1910)$	$1/2^+$	****	***	****	**	**		*
$\Delta(1920)$	$3/2^+$	***	***	***	***	**		**
$\Delta(1930)$	$5/2^-$	***	*	***	*	*		
$\Delta(1940)$	$3/2^-$	**	*	**	*			*
$\Delta(1950)$	$7/2^+$	****	****	****	**	***		
$\Delta(2000)$	$5/2^+$	**	*	**	*		*	
$\Delta(2150)$	$1/2^-$	*		*				
$\Delta(2200)$	$7/2^-$	***	***	**	***	**		
$\Delta(2300)$	$9/2^+$	**		**				
$\Delta(2350)$	$5/2^-$	*		*				
$\Delta(2390)$	$7/2^+$	*		*				
$\Delta(2400)$	$9/2^-$	**	**	**				
$\Delta(2420)$	$11/2^+$	****	*	****				
$\Delta(2750)$	$13/2^-$	**		**				
$\Delta(2950)$	$15/2^+$	**		**				

***** More/Less**

Δ^*, 12/10

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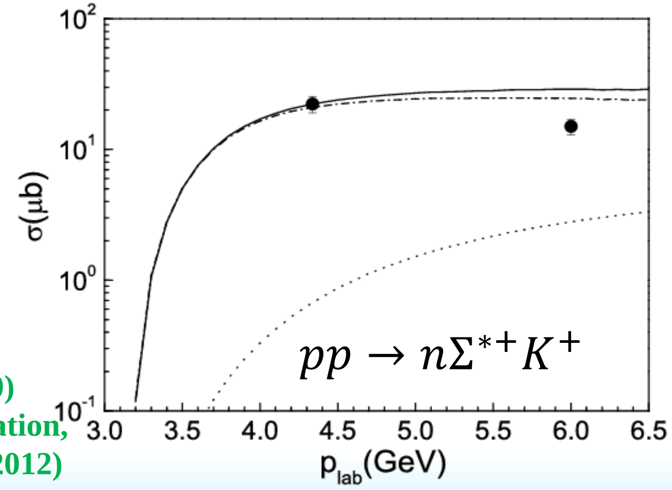
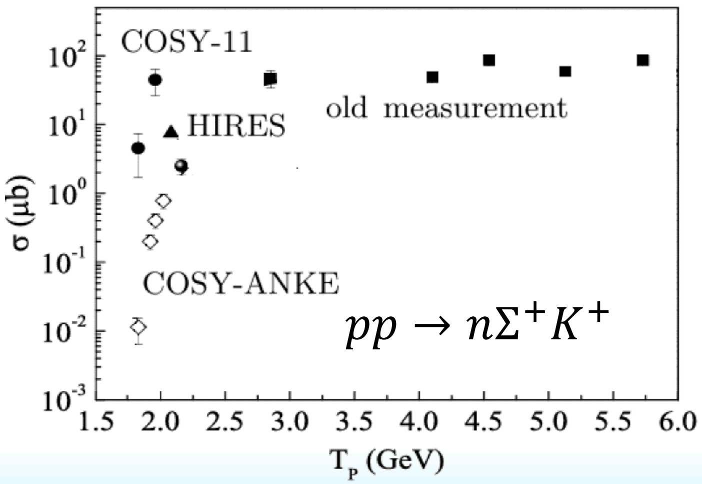
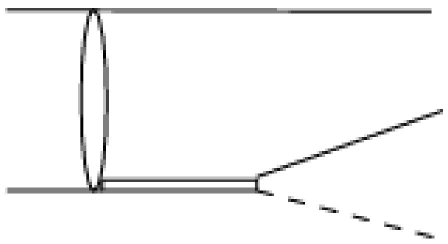
J.J.Xie & B.S.Zou, PLB649 (2007) 405
Ju-Jun Xie, En Wang, Bing-Song Zou, PRC 90 (2014) 2, 025207
Xiao-Yun Wang, Xu Cao, Ju-Jun Xie, Xu-Rong Chen, PRC 92 (2015) 015202

S. Klein, et al.
PRD 1, 3019 (1970)
HADES Collaboration,
PRC 85, 035203 (2012)





Physics for Proton Beam

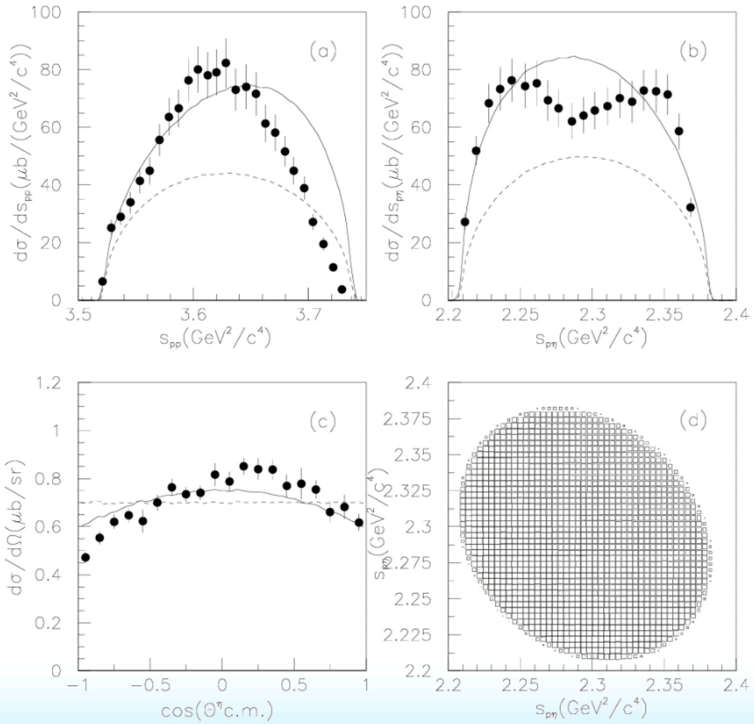


- **Excited Baryon ---** N^*

$$pp \to n\Delta^* \to n(p\pi^+/\Sigma^+K^+)$$

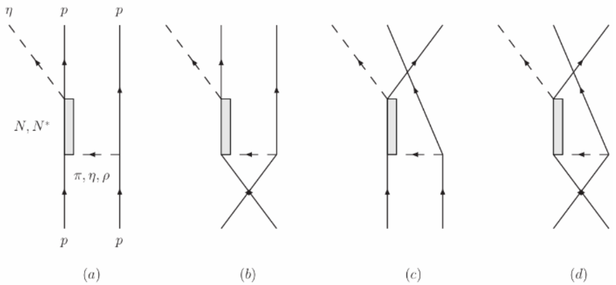
Zhen Ouyang, Ju-Jun Xie, Bing-Song Zou, Hu-Shan Xu, *Nucl.Phys.A* 821 (2009) 220-234

Q.F. Lyu, D.M. Li, CPC 39(2015) 113104



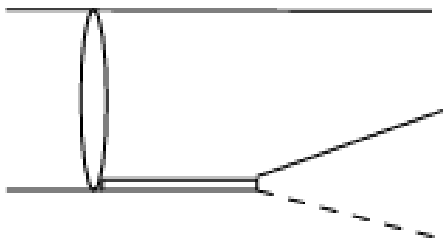
$$pp \to pp\eta$$

Resonance	Width(GeV)	Decay channel	Branching ratios	$g^2/4\pi$	Cut-off(GeV)
$N^*(1535)$	0.15	$N\pi$	0.45	0.037	0.8
		$N\eta$	0.42	0.28	0.8
		$N\rho$	0.02	5.55	0.8
$N^*(1650)$	0.15	$N\pi$	0.70	0.052	1.5
		$N\eta$	0.10	0.036	1.5
		$N\rho$	0.01	0.0064	1.5
$N^*(1710)$	0.1	$N\pi$	0.125	0.072	1.5
		$N\eta$	0.20	0.97	1.5
		$N\rho$	0.15	0.019	1.5
$N^*(1720)$	0.25	$N\pi$	0.11	0.11	1.5
		$N\eta$	0.04	0.35	1.5
		$N\rho$	0.775	635.11	1.5



Coupled channel effect ??
ΣK and ΛK

Physics for Proton Beam



- **Excited Baryon** --- P_s pentaquark states

$K\Sigma(1190) \sim 1685$ MeV
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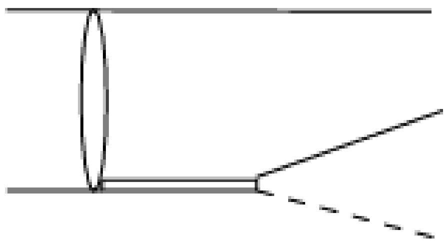
$K^*\Sigma^*(1385) \sim 2277$ MeV

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

Physics for Proton Beam



- **Excited Baryon ––– P_s** pentaquark states

$K\Sigma(1190) \sim 1685$ MeV
$K\Sigma^*(1385) \sim 1880$ MeV
$K^*\Sigma(1190) \sim 2082$ MeV
$K^*\Sigma^*(1385) \sim 2277$ MeV

$N^*(2080)$ and $N^*(2270)$ instead of

Previous $N^*(2000, \frac{5}{2}^+)$ and $N^*(2300, \frac{1}{2}^+)$

in the analysis of $\gamma p \to p\phi$

Shu-Ming Wu, Fei Wang, Bing-Song Zou, *PRC* 108 (2023) 4, 045201

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

Production of exotic hadrons in pp and nuclear collisions*

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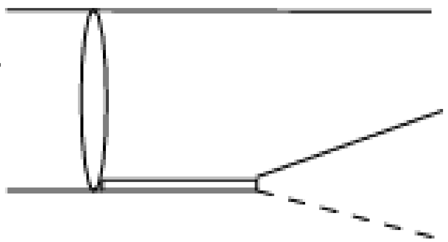
Nucl.Sci.Tech. 36 (2025) 4, 55

Physics for Proton Beam



- **Excited Baryon** --- P_s pentaquark states

$K\Sigma(1190) \sim 1685$ MeV
$K\Sigma^*(1385) \sim 1880$ MeV
$K^*\Sigma(1190) \sim 2082$ MeV
$K^*\Sigma^*(1385) \sim 2277$ MeV

$N^*(2080)$ and $N^*(2270)$ instead of

Previous $N^*(2000, \frac{5}{2}^+)$ and $N^*(2300, \frac{1}{2}^+)$

in the analysis of $\gamma p \to p\phi$

Shu-Ming Wu, Fei Wang, Bing-Song Zou, *PRC* 108 (2023) 4, 045201

$pp \to pp\phi$???

Ju-Jun Xie, Bing-Song Zou, Huan-Ching Chiang, PRC77 (2008) 015206

Bing-Song Zou, Ju-Jun Xie, *Nucl.Phys.A* 834 (2010) 544C

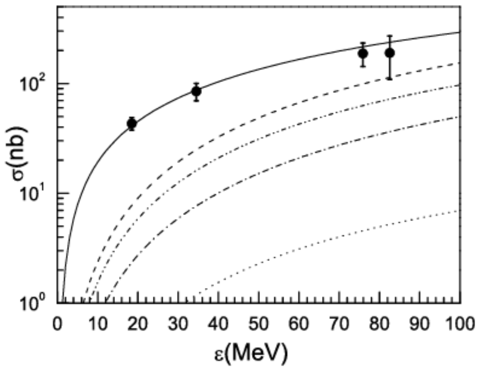
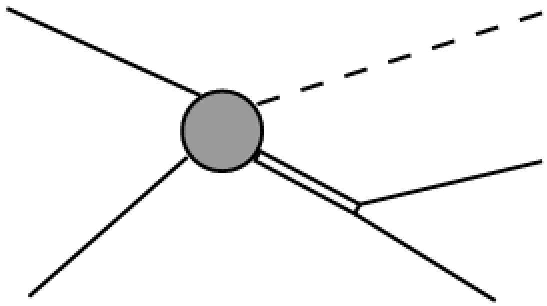


Figure 6. Total cross section vs excess energy for the $pp \to pp\phi$ reaction.

Now Current energy is enough to produce $N^*(2080)$ and $N^*(2270)$

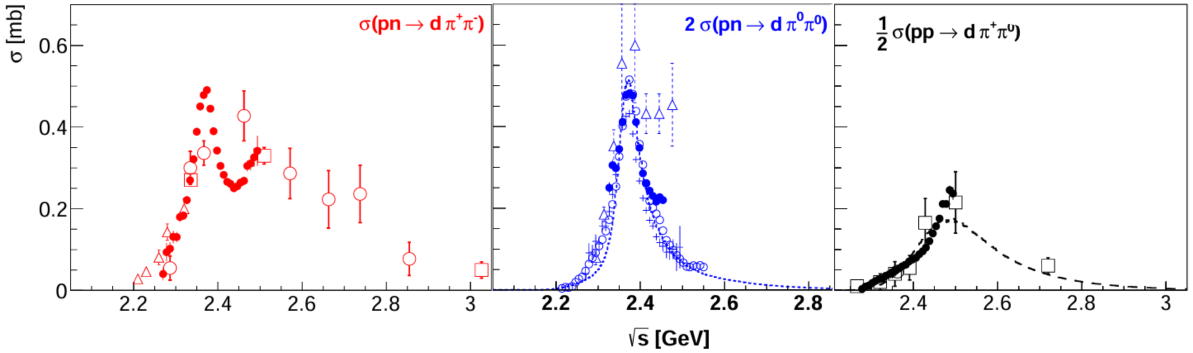
Particle	J^P	overall	$N\gamma$	$N\pi$	$\Delta\pi$	$N\sigma$	$N\eta$	ΛK	ΣK	$N\rho$	$N\omega$	$N\eta\prime$
N	$1/2^+$	****										
$N(1440)$	$1/2^+$	****	****	****	****	***						
$N(1520)$	$3/2^-$	****	****	****	****	**	****					
$N(1535)$	$1/2^-$	****	****	****	***	*	****					
$N(1650)$	$1/2^-$	****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

Physics for Proton Beam



- **Double-baryon ——— d* (2380)**

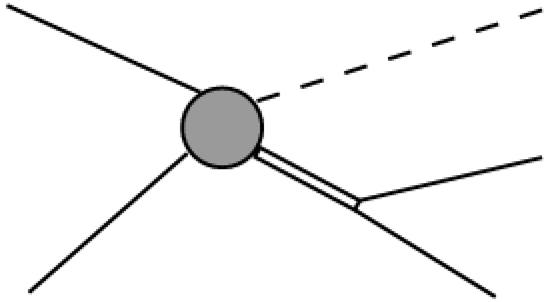
1. $pp \to X\pi\pi$, X has a baryon number of two
2. $pp \to D_{30}\pi^-\pi^- \to p\pi^+p\pi^+\pi^-\pi^-$, search d*(2380) with $I = I_z = 3$



$$I(J^P) = 0(3^+),\ M \approx 2380 \text{ MeV and } \Gamma \approx 70 \text{ MeV}$$

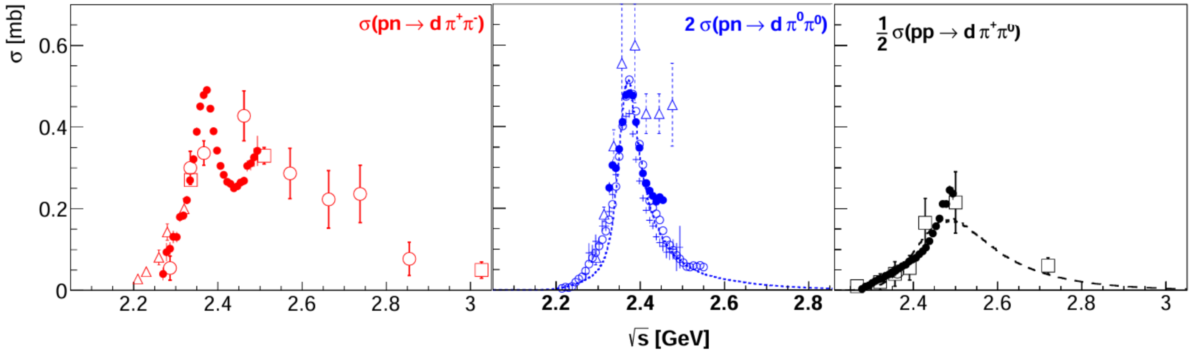
H. Clement, *Prog.Part.Nucl.Phys.* 93 (2017) 195
WASA-at-COSY, PRL 112, 202301 (2014)
……

Physics for Proton Beam



- **Double-baryon** — d*（2380） Hyper deute

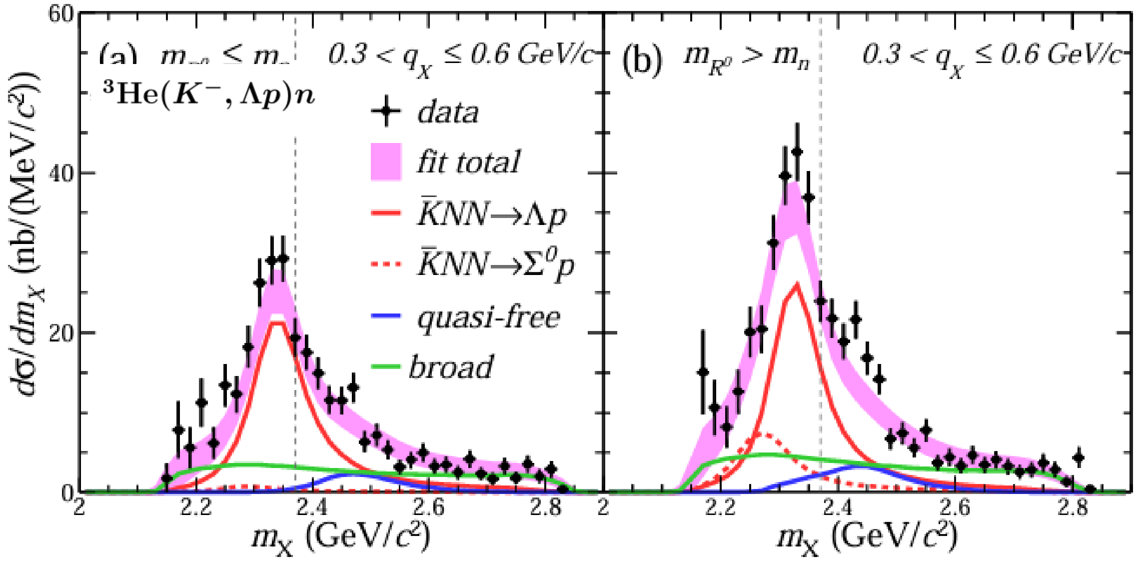
1. $pp \to X\pi\pi$, X has a baryon number of two
2. $pp \to D_{30}\pi^-\pi^- \to p\pi^+p\pi^+\pi^-\pi^-$, search d*(2380) with $I = I_z = 3$
3. $pd \to \mathrm{d}_\Lambda K$, Hyper deuteron



$$I(J^P) = 0(3^+),\ M \approx 2380\ \text{MeV and } \Gamma \approx 70\ \text{MeV}$$

$M_K = 2.328 \pm 0.003(\text{stat.})^{+0.004}_{-0.003}(\text{syst.})\ \text{GeV}/c^2$

$\Gamma_K = 100 \pm 7(\text{stat.})^{+19}_{-9}(\text{syst.})\ \text{MeV}$,



H. Clement, *Prog.Part.Nucl.Phys.* 93 (2017) 195

WASA-at-COSY, PRL 112, 202301 (2014)

……

J-PARC E15 Collaboration, *Phys.Rev.C* 102 (2020) 4, 044002

Physics for K Beam

Particle	J^P	overall	$N\gamma$	$N\pi$	$\Delta\pi$	$N\sigma$	$N\eta$	ΛK	ΣK	$N\rho$	$N\omega$
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.

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

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

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

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−	***	**	***	**	**
$\Xi(1950)$		***	**	**		*
$\Xi(2030)$		***		**	***	
$\Xi(2120)$		*		*		
$\Xi(2250)$		**				
$\Xi(2370)$		**				
$\Xi(2500)$		*		*	*	

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

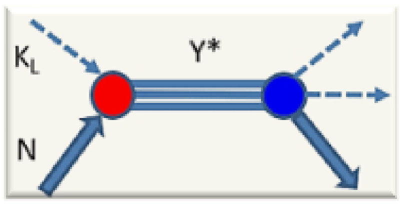
***** & More/Less， N^*,21/7， Δ^*,12/10， Λ^*,14/9， Σ^*,9/17, Ξ^*,6/5, Ω^*,3/2**

Physics for K Beam

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 $S = -2$	$K_L p \to K^+ \Xi^0$ $K_L p \to K^+ \Xi^{0*}$	$K_L n \to K^0 \Xi^0$ $K_L n \to K^0 \Xi^{0*}$
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^*:	$K_L^0 p \to K^+ K^+ \Omega^*$



***** & More/Less， N^*,21/7， Δ^*,12/10， Λ^*,14/9， Σ^*,9/17, Ξ^*,6/5， Ω^*,3/2**

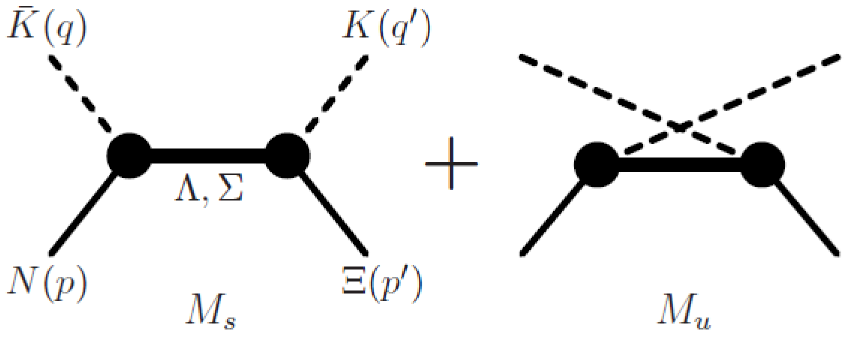
$\Xi(1620)^-$ production in K^-p scattering process #15

Quan-Yun Guo (Southeast U., Nanjing), Zi-Li Yue (Southeast U., Nanjing), Dian-Yong Chen (Southeast U., Nanjing and Lanzhou U. (main)) (Nov 28, 2023)

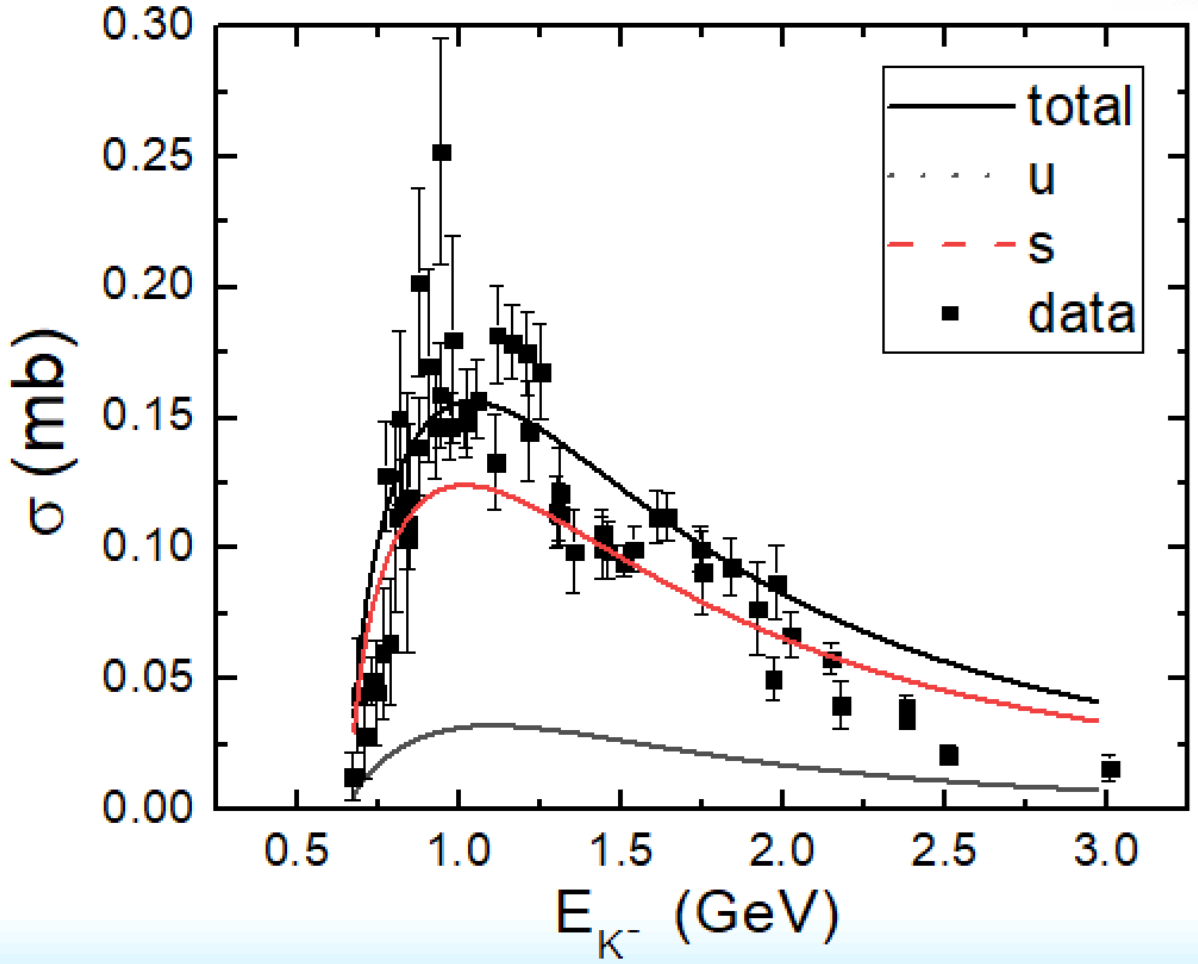
Published in: Eur.Phys.J.C 84 (2024) 4, 380 • e-Print: 2311.16920 [hep-ph]

$$K^-p \to K^+\Xi^-$$

邹老师的一个博士生正在研究

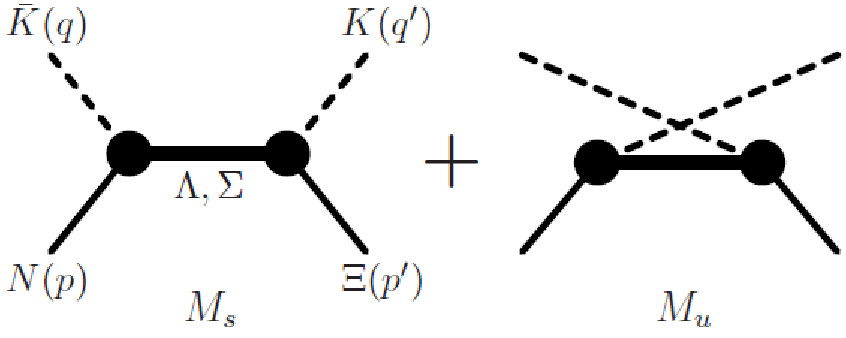


共振态粒子（R）	质量（MeV）	宽度（MeV）	$g_{KNR} * g_{K\Xi R}$
Λ	1116	0	46.31[3]
Σ	1189	0	47.47[3]
$\Lambda(1405)$	1405	50	1.501[2]
$\Lambda(1670)$	1670	35	0.054[2]
$\Lambda(1810)$	1810	150	7.840[2]
$\Lambda(1520)$	1520	16	0.646[1]
$\Sigma(1750)$	1750	90	0.250[2]
$\Sigma(1385)$	1385	36	18.00[3]
$\Sigma(1670)$	1670	60	7.840[2]



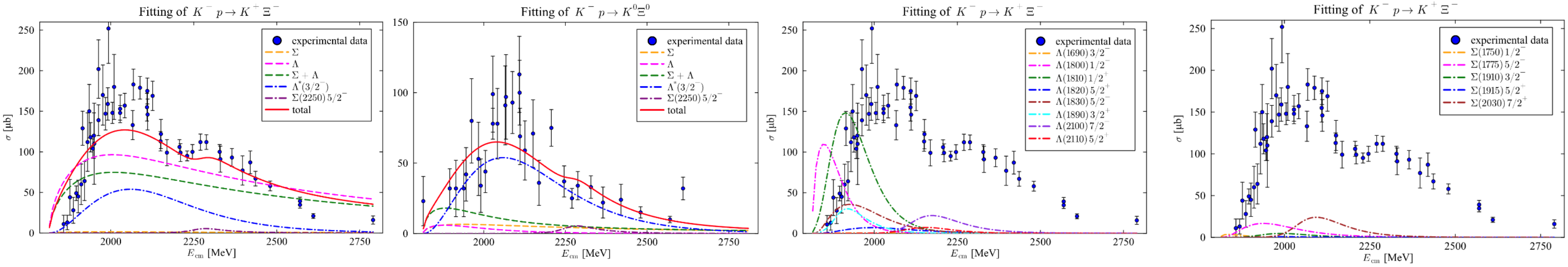
[1]D.A.Sharov, V.L.Korotkikh and D.E.Lanskoy, EPJA47(2011)109
[2]R.Shyam, O.Scholten and A.W.Thomas , PRC84(2011)042201
[3]B.C.Jackson, Y.Oh, H.Haberzettl and K.Nakayama, PRC91(2015)065208

$K^- p \to K^+ \Xi^-$



Resonances			m (MeV)	Γ (MeV)	$g_{\Lambda N \bar{K}}$	$g_{\Lambda \Xi K}$
$\Lambda(1690)$	$3/2^-$	$****$	1690	70	$5.4 \sim 6.6$	-
$\Lambda(1800)$	$1/2^-$	$***$	1800	200	$1.0 \sim 1.3$	-
$\Lambda(1810)$	$1/2^+$	$***$	1841	164	$1.5 \sim 3.9$	13.6
$\Lambda(1820)$	$5/2^+$	$****$	1820	80	$8.1 \sim 8.8$	not seen
$\Lambda(1830)$	$5/2^-$	$****$	1825	90	$0.6 \sim 0.9$	$186(< 114)$
$\Lambda(1890)$	$3/2^+$	$****$	1890	120	$1.1 \sim 1.3$	0.8
$\Lambda(2100)$	$7/2^-$	$****$	2100	200	$3.1 \sim 3.7$	$3.1(< 8.5)$
$\Lambda(2110)$	$5/2^+$	$***$	2090	250	$1.6 \sim 3.6$	~ 0

Resonances			m (MeV)	Γ (MeV)	$g_{\Sigma N \bar{K}}$	$g_{\Sigma \Xi K}$
$\Sigma(1750)$	$1/2^-$	$***$	1750	150	$0.45 \sim 0.64$	-
$\Sigma(1775)$	$5/2^-$	$****$	1775	120	$2.6 \sim 2.8$	-
$\Sigma(1910)$	$3/2^-$	$***$	1910	220	$0.96 \sim 2.1$	~ 0
$\Sigma(1915)$	$5/2^+$	$****$	1915	120	$2.0 \sim 3.4$	< 16.6
$\Sigma(2030)$	$7/2^+$	$****$	2030	180	$1.1 \sim 1.3$	$1.1(< 2.0)$



[1]D.A.Sharov, V.L.Korotkikh and D.E.Lanskoy, EPJA47(2011)109
[2]R.Shyam, O.Scholten and A.W.Thomas , PRC84(2011)042201
[3]B.C.Jackson, Y.Oh, H.Haberzettl and K.Nakayama, PRC91(2015)065208

To test a new molecule state of $\bar{K}^* N$: $\Lambda^*(1800)$ with 3/2-, which is the partner of $\Lambda^*(1405)$ as molecule of $\bar{K}N$

$K^- p \to K^+ \Xi^-(2030) \to K^+ K^- \Lambda$

Citation: P.A. Zyla *et al.* (Particle Data Group), Prog. Theor. Exp. Phys. **2020**, 083C01 (2020) and 2021 update

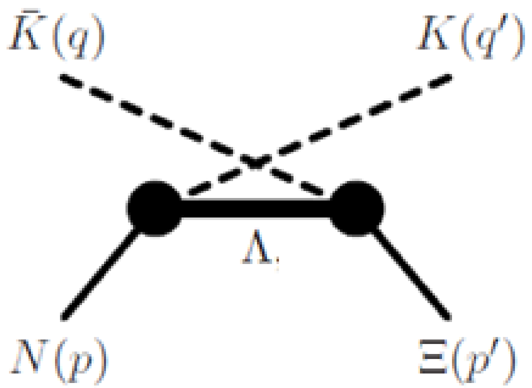
$\boxed{\Xi(2030)}$ $I(J^P) = \frac{1}{2}(\geq \frac{5}{2}^?)$ Status: ∗∗∗

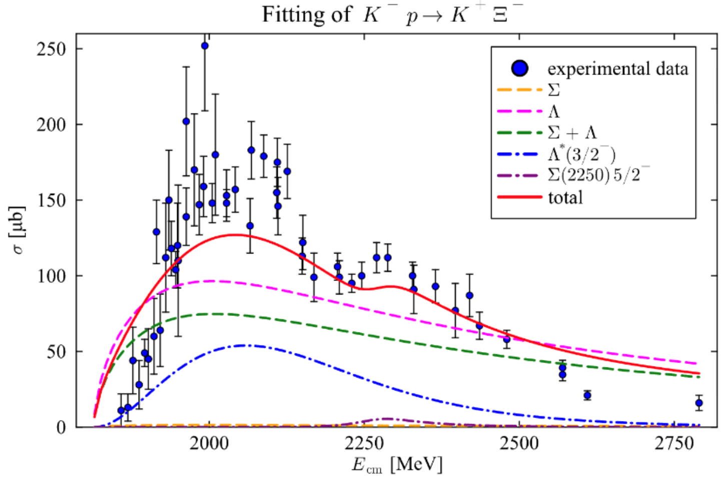
The evidence for this state has been much improved by HEMINGWAY 77, who see an eight standard deviation enhancement in $\Sigma\overline{K}$ and a weaker coupling to $\Lambda\overline{K}$. ALITTI 68 and HEMINGWAY 77 observe no signals in the $\Xi\pi\pi$ (or $\Xi(1530)\pi$) channel, in contrast to DIBIANCA 75. The decay $(\Lambda/\Sigma)\overline{K}\pi$ reported by BARTSCH 69 is also not confirmed by HEMINGWAY 77.

A moments analysis of the HEMINGWAY 77 data indicates at a level of three standard deviations that $J \geq 5/2$.

$\Xi(2030)$ MASS

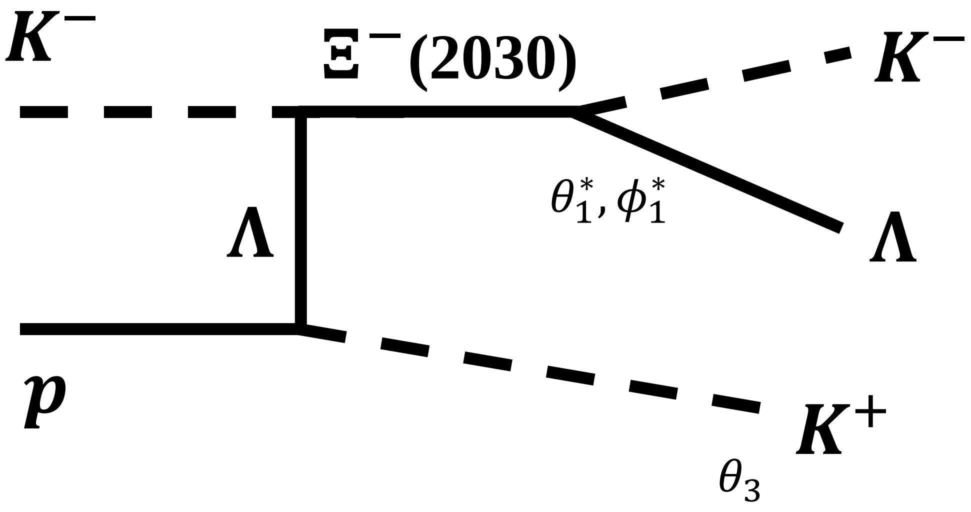
VALUE (MeV)	*EVTS*	*DOCUMENT ID*		*TECN*	*CHG*	*COMMENT*
2025 ± 5 OUR ESTIMATE						
2025.1± 2.4 OUR AVERAGE	Error includes scale factor of 1.3. See the ideogram below.					
2022 ± 7		JENKINS	83	MPS	−	$K^- p \to K^+$ MM
2024 ± 2	200	HEMINGWAY	77	HBC	−	$K^- p$ 4.2 GeV/c
2044 ± 8		DIBIANCA	75	DBC	−0	$\Xi\pi\pi$, $\Xi^*\pi$
2019 ± 7	15	ROSS	73C	HBC	−0	$\Sigma\overline{K}$
2030 ±10	42	ALITTI	69	HBC	−	$K^- p$ 3.9–5 GeV/c
2058 ±17	40	BARTSCH	69	HBC	−0	$K^- p$ 10 GeV/c



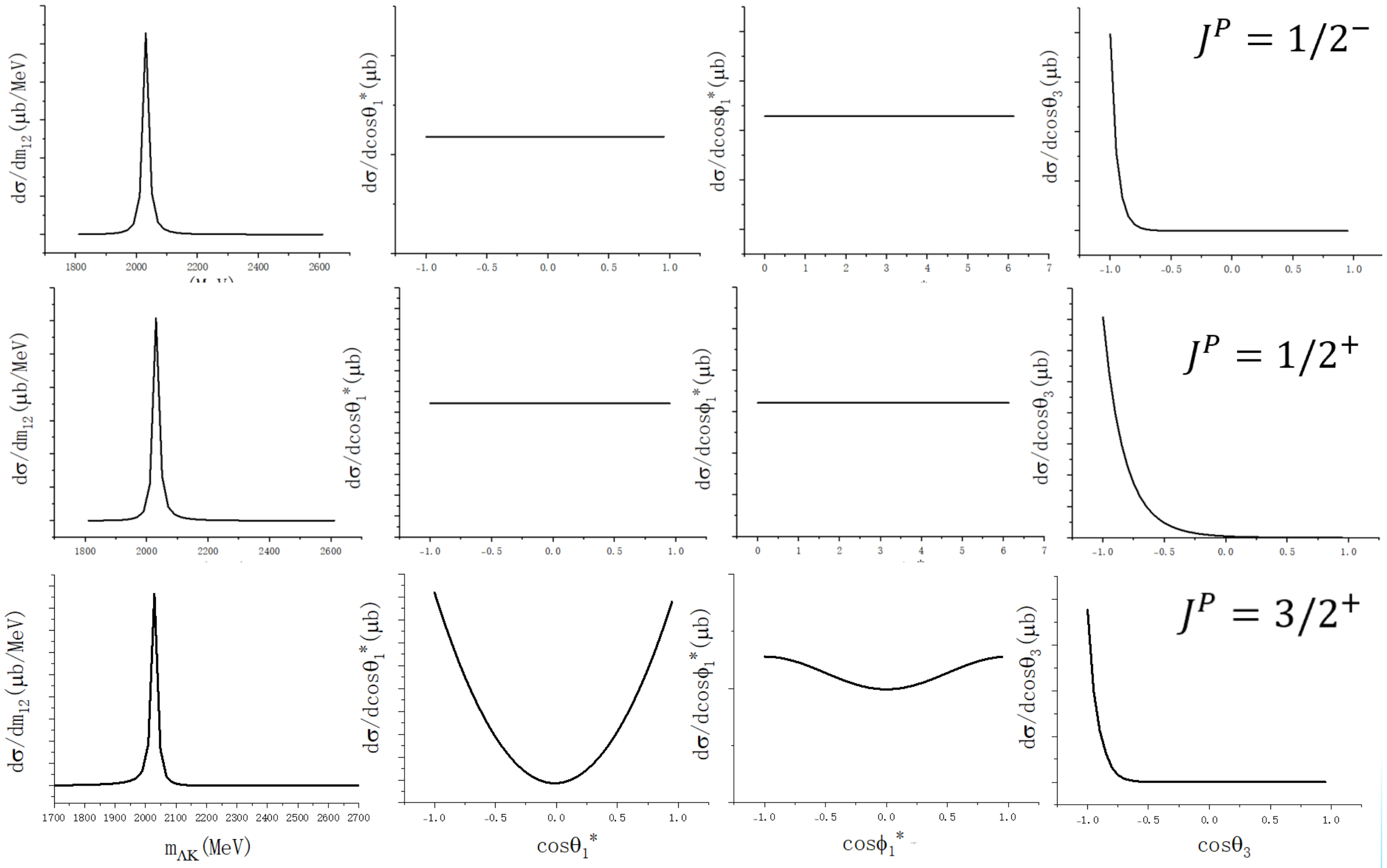


Predict the angular distributions of $\Xi^-(2030)$ with different spin and parity assumption

$K^- p \rightarrow K^+ \Xi^-(2030) \rightarrow K^+ K^- \Lambda$



Predict the angular distributions of $\Xi^-(2030)$ with different spin and parity assumption



Summary and Outlook

- Understanding non-perturbative QCD and confinement currently relies on phenomenological approaches to summarize patterns, while further theoretical insights require extensive precise experimental data.
- High-luminosity proton beams and Kaon beams enable the discovery and confirmation of numerous hadronic resonance states.
- We anticipate rich hadronic physics experiments at the HHaS

Thanks