中微子束流产生超子物理
HIAF轻强子谱

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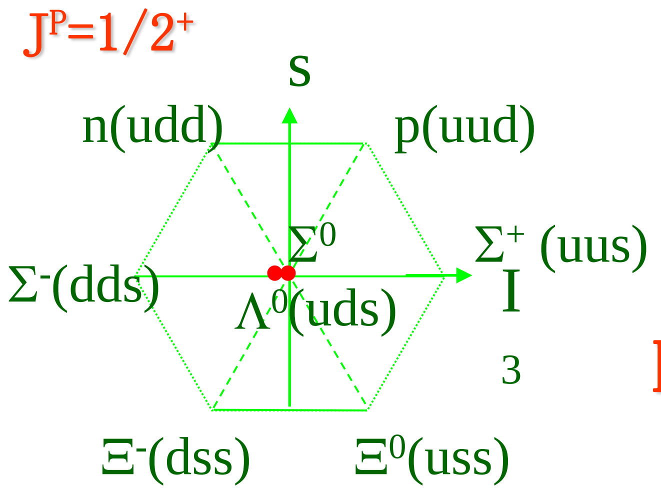
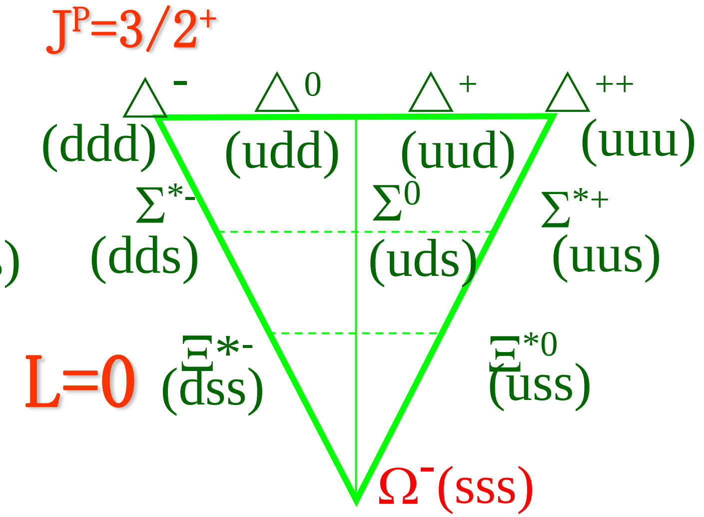
传统夸克模型 vs 五夸克态

- 三夸克模型





激发态L=1, $J^P=1/2^-$

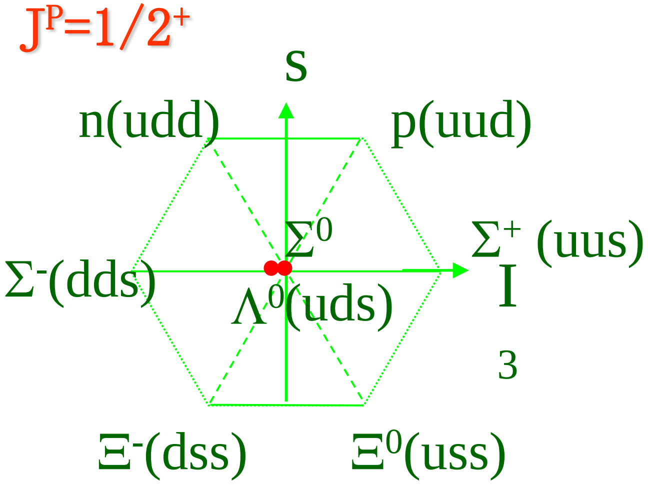
$N^*(1535), \Sigma^*(1620), \Lambda^*(1405), \Xi^*(1690?)$

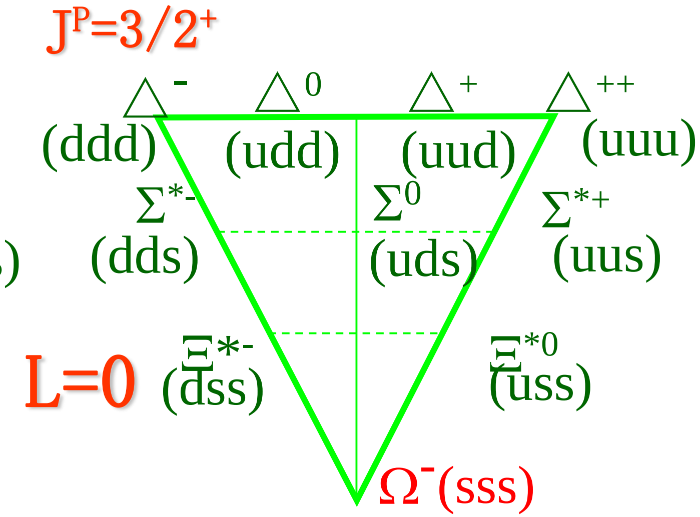
$N(940),\quad \Sigma(1189),\quad \Lambda(1115),\quad \Xi(1314)$

三夸克模型一定有问题

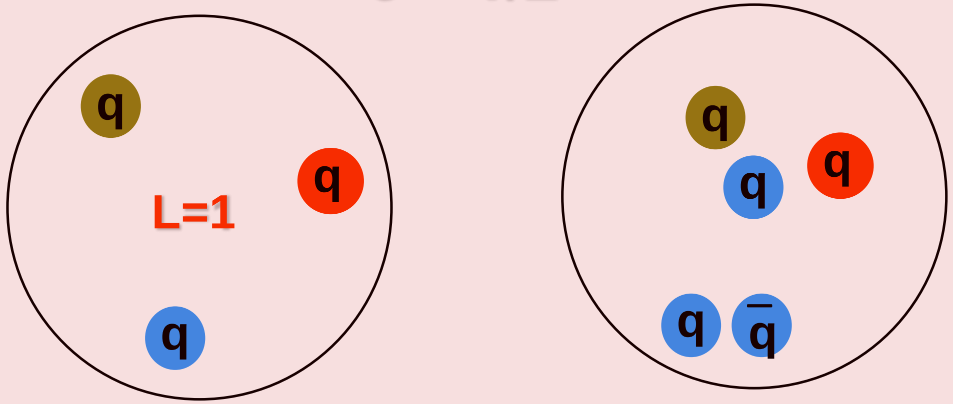
传统夸克模型 vs 五夸克态

- 三夸克模型





$J^P=1/2^-$



qqq with L=1 VS qqqqq in S-wave

Two possible patterns !

激发态L=1, $J^P=1/2^-$

$N^*(1535), \Sigma^*(1620), \Lambda^*(1405), \Xi^*(1690?)$

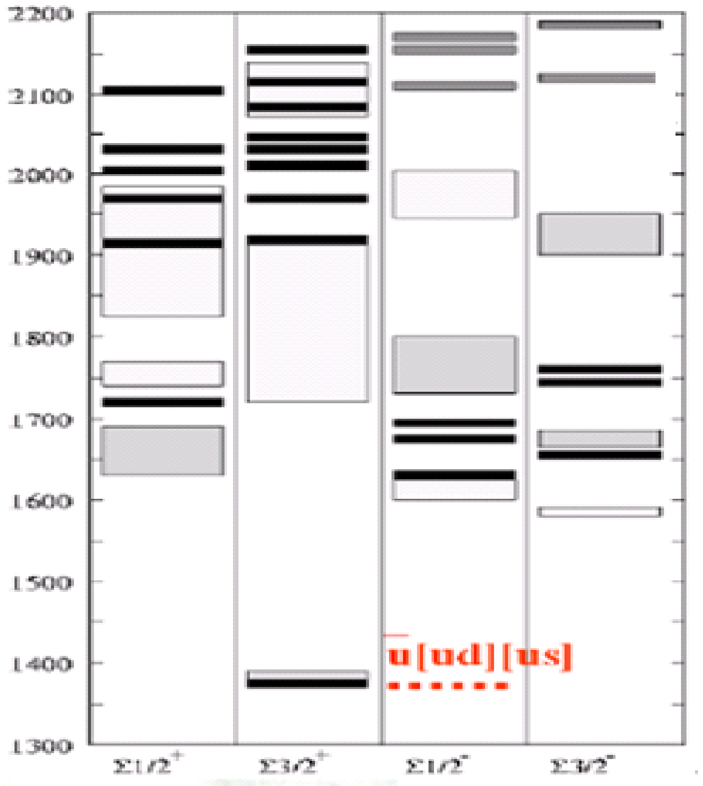
$N(940)$, $\Sigma(1189)$, $\Lambda(1115)$, $\Xi(1314)$

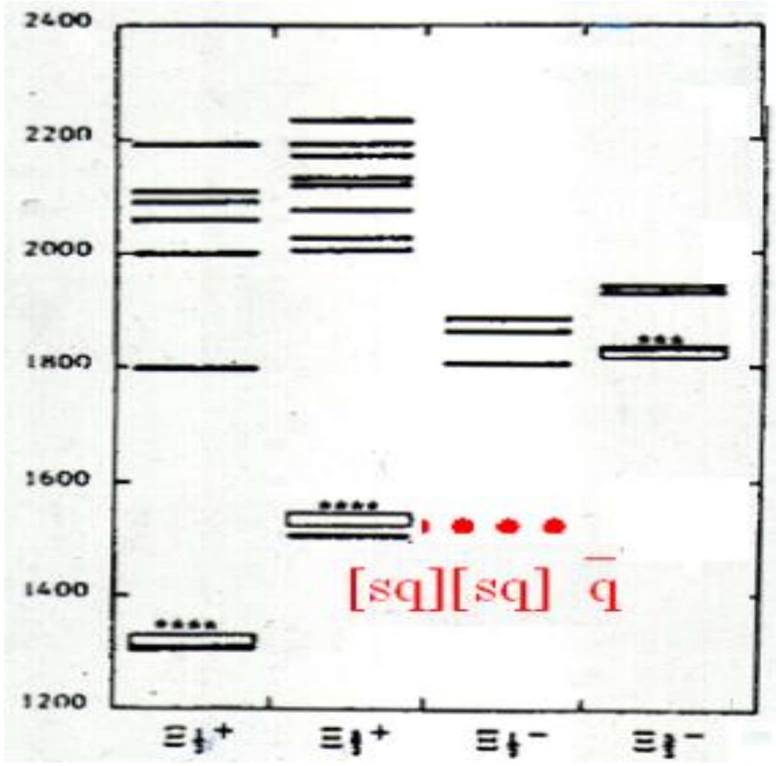
三夸克模型一定有问题

传统夸克模型 vs 五夸克态

Λ*	[ud][sq] $\bar{q}$	~	1405 MeV
Σ*	[us][du] $\bar{d}$	~	1360 MeV
Ξ*	[us][ds] $\bar{u}$	~	1520 MeV

$J^P=1/2^-$

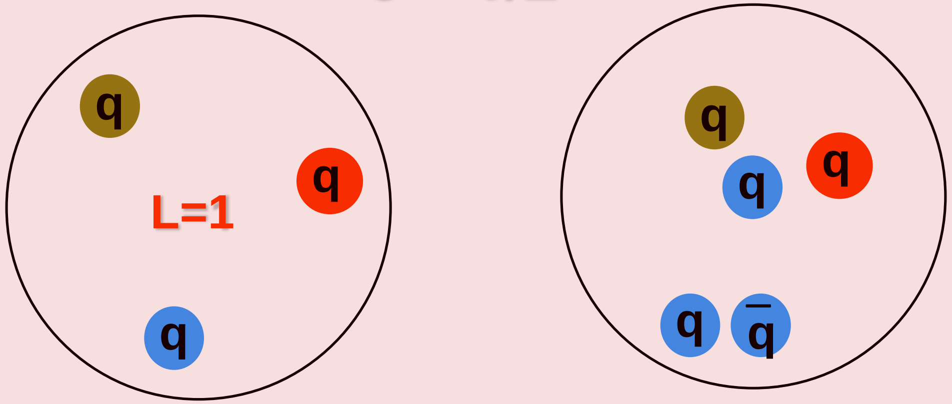




五夸克的基态往往比三夸克的第一轨道激发态要低

传统夸克模型 vs 五夸克态

$J^P=1/2^-$



qqq with L=1 VS qqqqq in S-wave

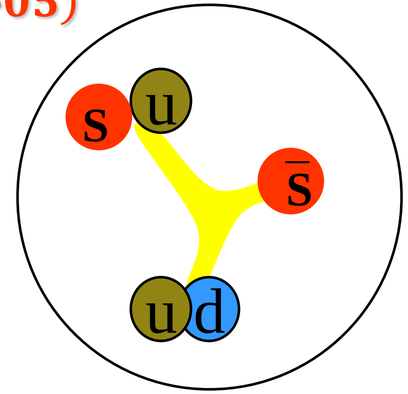
Two possible patterns !

Volume 2, Number 10 PHYSICAL REVIEW LETTERS May 15, 1959

POSSIBLE RESONANT STATE IN PION-HYPERON SCATTERING*

R. H. Dalitz and S. F. Tuan
Enrico Fermi Institute for Nuclear Studies and Department of Physics, University of Chicago, Chicago, Illinois
(Received April 27, 1959)

$\Lambda^*(1405)$



penta-quark

C. Helminen and D. O. Riska, NPA699, 624(2002).
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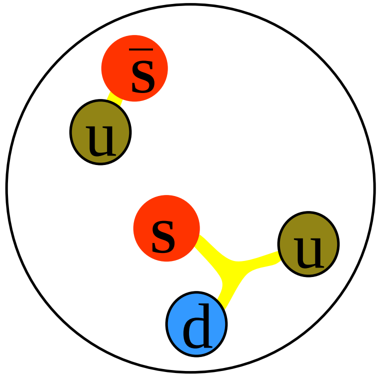


meson cloud/molecule

N. Kaiser, P. B. Siegel, and W. Weise, PLB 362,23 (1995).
D. Jido, J. A. Oller, E. Oset, A. Ramos, and U. G.Meissner, NPA725, 181 (2003).

超子谱的研究

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

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

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

三星以上/以下的，N^*，**21/7**个，Λ^*, **14/9**个，Σ^*, **9/17**个

背景：研究超子物理的反应

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

问题：多强子末态带来的困扰！

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

问题：束流能量选择有限制！

背景：研究超子物理的反应

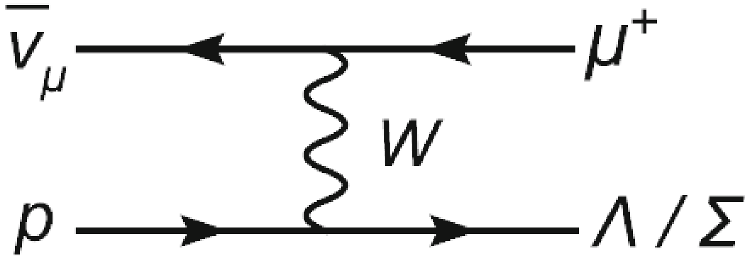
$\gamma p \to KY^*$, $\pi p \to KY^*$, $e^+e^- \to Y\bar{Y}^*$, $ep \to eKY^*$, $pp \to KNY^*$

问题：多强子末态带来的困扰！

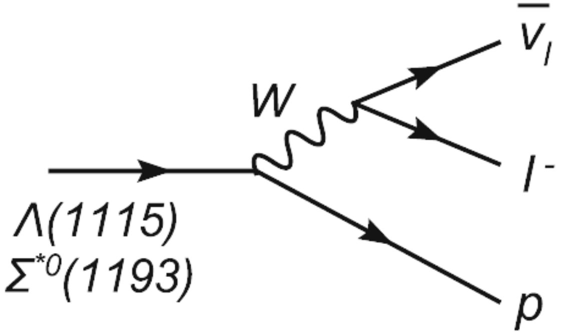
$K^- p \to Y^*$

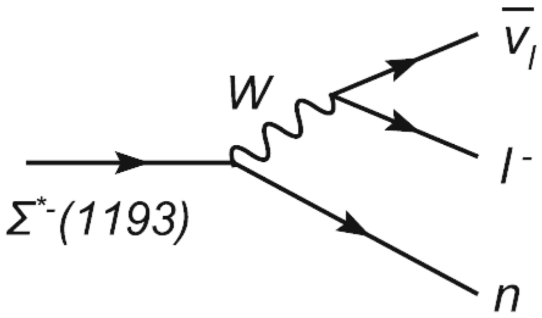
问题：束流能量选择有限制！

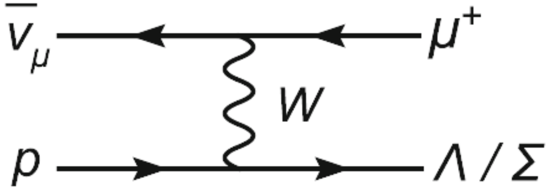
$\bar{\nu} p \to l^+ Y^*$



超子反应振幅计算





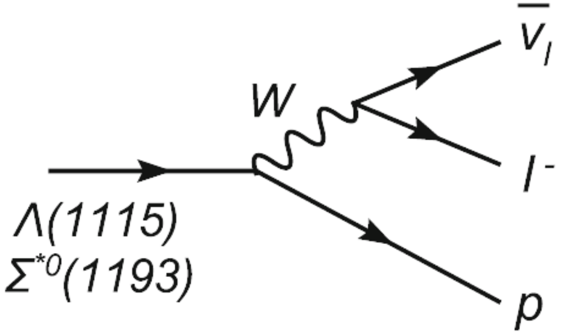


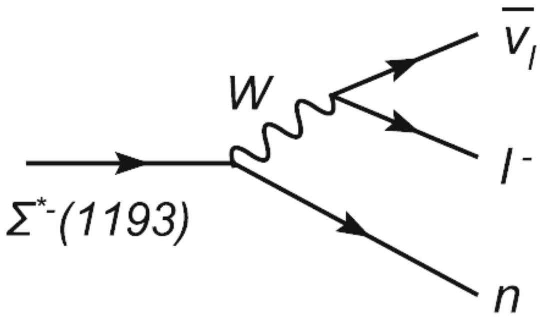
$$\mathcal{M} = T_1^\mu T_2^\nu G_{W\ \mu\nu} \qquad T_1^\mu = \sqrt{\frac{G_F m_W}{\sqrt{2}}}\left(\bar{l}\gamma^\mu(1-\gamma^5)\nu_l + h.c.\right) \qquad G_W^{\mu\nu} = \frac{-g^{\mu\nu} + p_W^\mu p_W^\nu / m_W^2}{p_W^2 - m_W^2}$$

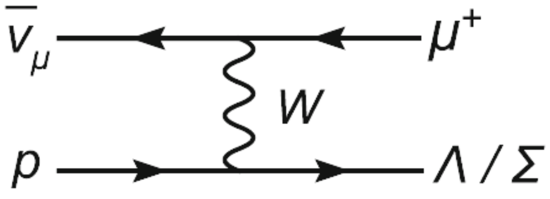
$$d\sigma = \frac{(2\pi)^4}{2E_\nu}\frac{1}{2}\sum_{s_z^\nu,\, s_z^{N1}}\sum_{s_z^l,\, s_z^{N2}} |\mathcal{M}|^2 \delta^{(4)}_{(p_\nu + p_{N_1} - p_l - p_{N_2})} \frac{d^3\mathbf{p}_{N_1} m_{N_1}}{(2\pi)^3 E_{N_1}} \frac{d^3\mathbf{p}_l m_l}{(2\pi)^3 E_l}$$

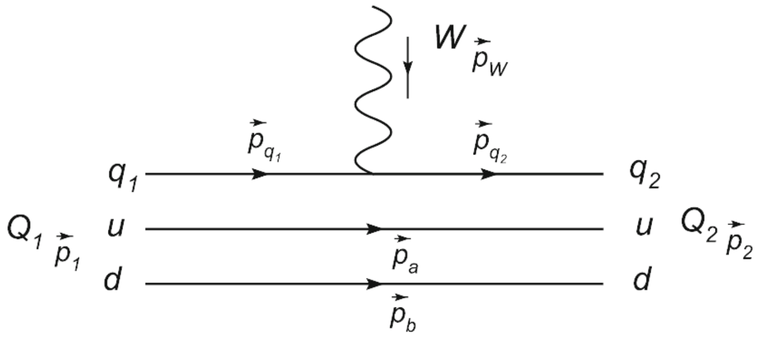
$$d\Gamma = \frac{(2\pi)^4}{2M_\Lambda}\frac{1}{2}\sum_{s_z^\Lambda}\sum_{s_z^\nu, s_z^l,\, s_z^p} |\mathcal{M}|^2 \delta^{(4)}_{(p_\nu + p_l + p_p)} \frac{d^3\mathbf{p}_p m_p}{(2\pi)^3 E_p} \frac{d^3\mathbf{p}_\nu}{(2\pi)^3 2E_\nu} \frac{d^3\mathbf{p}_l m_l}{(2\pi)^3 E_l}$$

W-强子对的顶点计算









基于强子层次的计算

$$T^{\mu}_{2\,BNW} = \sqrt{\frac{G_F m_W}{\sqrt{2}}}|v_{us}|(V^\mu + A^\mu)$$

$$\text{with}\quad V^\mu = \bar{B}\left(f_1(q^2)\gamma^\mu - i\frac{f_2(q^2)\sigma^{\mu\nu}q_\nu}{m_B} + f_3(q^2)\frac{q_\mu}{m_B}\right)N + h.c.,$$

$$A^\mu = \bar{B}\left(g_1(q^2)\gamma^\mu - i\frac{g_2(q^2)\sigma^{\mu\nu}q_\nu}{m_B} + g_3(q^2)\frac{q_\mu}{m_B}\right)\gamma^5 N + h.c.$$

$$f_1(q^2) = \frac{f_1(0)}{(1 - q^2/M_v^2)^2}$$

$$g_1(q^2) = \frac{g_1(0)}{(1 - q^2/M_a^2)^2}$$

$$f_2(q^2) = f_2(0).\ ?$$

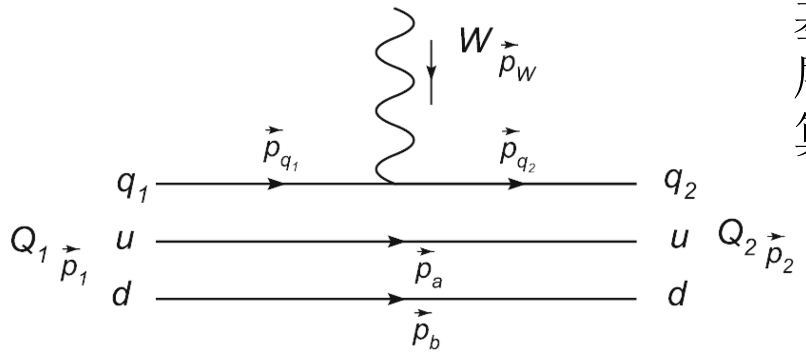
基于夸克层次的计算

$$T_2^\nu(\mathbf{p}_w, s_z^{Q_1}, s_z^{Q_2}) = \int d\mathbf{p}_a d\mathbf{p}_b d\mathbf{p}_{q_1} d\mathbf{p}_{q_2}\,\delta(\mathbf{p}_a+\mathbf{p}_b+\mathbf{p}_{q_1})\,\delta(\mathbf{p}_{q_2}-\mathbf{p}_{q_1}-\mathbf{p}_w) \times \sqrt{\frac{G_F m_W}{\sqrt{2}}}|v_{q1q2}|$$

$$\times \sum_{s_z^{q2},\, s_z^{q1}} \langle X^{Q_2},\, s_z^{Q_2},\, \Phi^{Q_2}|\chi^+_{q2,\, s_z^{q2}}\chi_{q1,\, s_z^{q1}}|X^{Q_1},\, s_z^{Q_1},\, \Phi^{Q_1}\rangle$$

$$\times\, \bar{u}_{q2}(\mathbf{p}_{q2},\, s_z^{q2})\gamma^\nu(1-\gamma^5)u_{q1}(\mathbf{p}_{q1},\, s_z^{q1}),$$

W-强子对的顶点计算



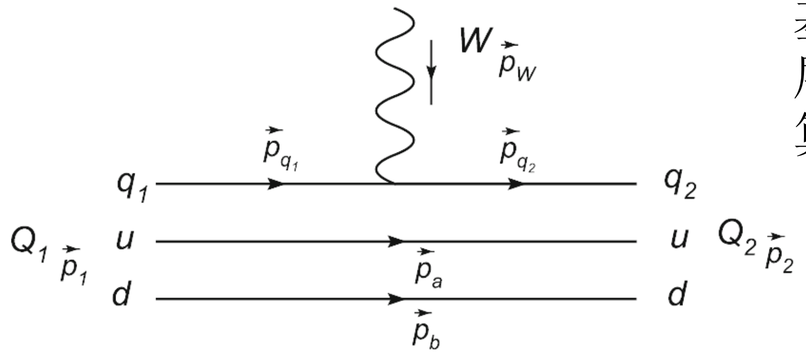
基于夸克层次的计算

$$T_2^{\nu}(\mathbf{p}_w, s_z^{Q_1}, s_z^{Q_2}) = \int d\mathbf{p}_a d\mathbf{p}_b d\mathbf{p}_{q_1} d\mathbf{p}_{q_2} \delta(\mathbf{p}_a+\mathbf{p}_b+\mathbf{p}_{q_1}) \delta(\mathbf{p}_{q_2}-\mathbf{p}_{q_1}-\mathbf{p}_w) \times \sqrt{\frac{G_F m_W}{\sqrt{2}}} |v_{q_1 q_2}|$$
$$\times \sum_{s_z^{q_2},\, s_z^{q_1}} \langle X^{Q_2},\ s_z^{Q_2},\ \Phi^{Q_2} | \chi^{+}_{q_2,\, s_z^{q_2}} \chi_{q_1,\, s_z^{q_1}} | X^{Q_1},\ s_z^{Q_1},\ \Phi^{Q_1} \rangle$$
$$\times\ \bar{u}_{q_2}(\mathbf{p}_{q_2},\ s_z^{q_2}) \gamma^{\nu} (1-\gamma^5) u_{q_1}(\mathbf{p}_{q_1},\ s_z^{q_1}),$$

$$|N(939)\rangle = 0.90|N_8^2 S_s\rangle + 0.34|N_8^2 S_s'\rangle - 0.27|N_8^2 S_M\rangle,$$
$$|\Lambda(1115)\rangle = 0.93|\Lambda_8^2 S_s\rangle + 0.30|\Lambda_8^2 S_s'\rangle - 0.20|\Lambda_8^2 S_M\rangle,$$

$$\left|B_8^2 S_s, \frac{1}{2}^+\right\rangle = \frac{1}{\sqrt{2}} \left(|B\rangle_\lambda \left|\frac{1}{2}, s_z\right\rangle_\lambda + |B\rangle_\rho \left|\frac{1}{2}, s_z\right\rangle_\rho \right) \Phi_{000}(\mathbf{q}_\lambda, \mathbf{q}_\rho)$$

W-强子对的顶点计算



基于夸克层次的计算

$$T_2^{\nu}(\mathbf{p}_w, s_z^{Q_1}, s_z^{Q_2}) = \int d\mathbf{p}_a d\mathbf{p}_b d\mathbf{p}_{q_1} d\mathbf{p}_{q_2} \delta_{(\mathbf{p}_a+\mathbf{p}_b+\mathbf{p}_{q_1})} \delta_{(\mathbf{p}_{q_2}-\mathbf{p}_{q_1}-\mathbf{p}_w)} \times \sqrt{\frac{G_F m_W}{\sqrt{2}}} |v_{q_1 q_2}|$$
$$\times \sum_{s_z^{q_2},\, s_z^{q_1}} \langle X^{Q_2},\ s_z^{Q_2},\ \Phi^{Q_2} | \chi^{+}_{q_2,\, s_z^{q_2}} \chi_{q_1,\, s_z^{q_1}} | X^{Q_1},\ s_z^{Q_1},\ \Phi^{Q_1} \rangle$$
$$\times\ \bar{u}_{q_2}(\mathbf{p}_{q_2},\ s_z^{q_2}) \gamma^{\nu} (1-\gamma^5) u_{q_1}(\mathbf{p}_{q_1},\ s_z^{q_1}),$$

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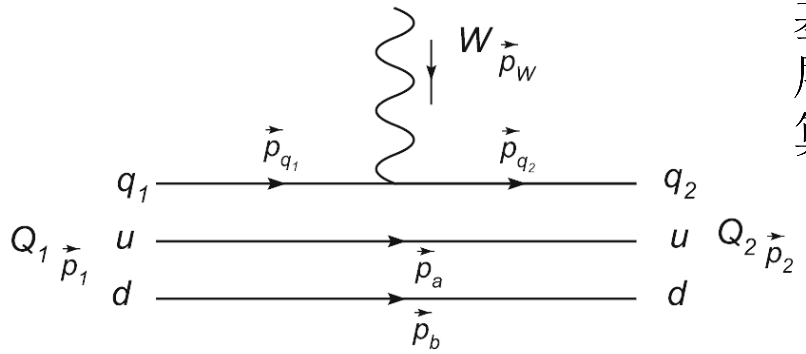
$$\left|B_8^2 S_s, \frac{1}{2}^{+}\right\rangle = \frac{1}{\sqrt{2}}\left(|B\rangle_\lambda \left|\frac{1}{2}, s_z\right\rangle_\lambda + |B\rangle_\rho \left|\frac{1}{2}, s_z\right\rangle_\rho\right) \Phi_{000}(\mathbf{q}_\lambda, \mathbf{q}_\rho)$$

味道波函数部分

$$_\lambda\langle \Lambda | \chi_s^{+} \chi_u | p \rangle_\lambda = 0,$$
$$_\lambda\langle \Lambda | \chi_s^{+} \chi_u | p \rangle_\rho = 0,$$
$$_\rho\langle \Lambda | \chi_s^{+} \chi_u | p \rangle_\lambda = 0,$$
$$_\rho\langle \Lambda | \chi_s^{+} \chi_u | p \rangle_\rho = \frac{\sqrt{6}}{3}.$$

W-强子对的顶点计算



基于夸克层次的计算

$$T_2^{\nu}(\mathbf{p}_w, s_z^{Q_1}, s_z^{Q_2}) = \int d\mathbf{p}_a d\mathbf{p}_b d\mathbf{p}_{q_1} d\mathbf{p}_{q_2} \delta_{(\mathbf{p}_a+\mathbf{p}_b+\mathbf{p}_{q_1})} \delta_{(\mathbf{p}_{q_2}-\mathbf{p}_{q_1}-\mathbf{p}_w)} \times \sqrt{\frac{G_F m_W}{\sqrt{2}}} |v_{q_1 q_2}|$$
$$\times \sum_{s_z^{q2},\, s_z^{q1}} \langle X^{Q_2},\ s_z^{Q_2},\ \Phi^{Q_2} | \chi^+_{q2,\, s_z^{q2}} \chi_{q1,\, s_z^{q1}} | X^{Q_1},\ s_z^{Q_1},\ \Phi^{Q_1} \rangle$$
$$\times \bar{u}_{q_2}(\mathbf{p}_{q_2},\ s_z^{q_2}) \gamma^{\nu} (1-\gamma^5) u_{q_1}(\mathbf{p}_{q_1},\ s_z^{q_1}),$$

$$|N(939)\rangle = 0.90|N_8^2 S_s\rangle + 0.34|N_8^2 S_s'\rangle - 0.27|N_8^2 S_M\rangle,$$
$$|\Lambda(1115)\rangle = 0.93|\Lambda_8^2 S_s\rangle + 0.30|\Lambda_8^2 S_s'\rangle - 0.20|\Lambda_8^2 S_M\rangle,$$

$$\left|B_8^2 S_s, \frac{1}{2}^+\right\rangle = \frac{1}{\sqrt{2}} \left(|B\rangle_\lambda \left|\frac{1}{2}, s_z\right\rangle_\lambda + |B\rangle_\rho \left|\frac{1}{2}, s_z\right\rangle_\rho \right) \Phi_{000}(\mathbf{q}_\lambda, \mathbf{q}_\rho)$$

味道波函数部分

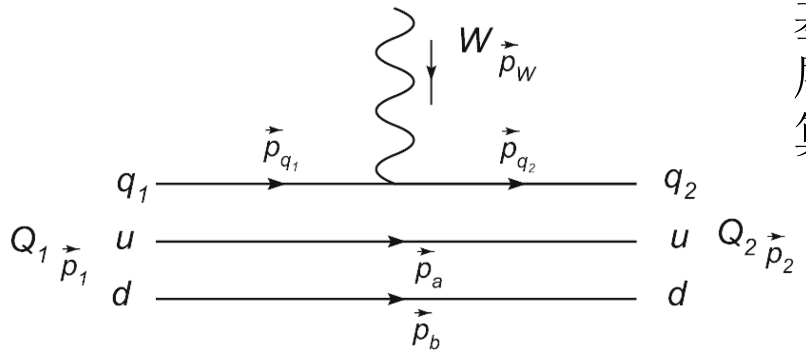
$${}_\lambda\langle \Lambda | \chi_s^+ \chi_u | p \rangle_\lambda = 0,$$
$${}_\lambda\langle \Lambda | \chi_s^+ \chi_u | p \rangle_\rho = 0,$$
$${}_\rho\langle \Lambda | \chi_s^+ \chi_u | p \rangle_\lambda = 0,$$
$${}_\rho\langle \Lambda | \chi_s^+ \chi_u | p \rangle_\rho = \frac{\sqrt{6}}{3}.$$

自旋波函数部分

$${}_\rho\left\langle \frac{1}{2}, s_z^\Lambda | \hat{O}^\mu | \frac{1}{2}, s_z^p \right\rangle_\rho = O^\mu(s_z^\Lambda, s_z^p),$$
$${}_\rho\left\langle \frac{1}{2}, s_z^\Lambda | \hat{O}^\mu | \frac{1}{2}, s_z^p \right\rangle_\lambda = 0,$$
$${}_\lambda\left\langle \frac{1}{2}, s_z^\Lambda | \hat{O}^\mu | \frac{1}{2}, s_z^p \right\rangle_\rho = 0,$$
$${}_\lambda\left\langle \frac{1}{2}, s_z^\Lambda = \frac{1}{2} | \hat{O}^\mu | \frac{1}{2}, s_z^p = \frac{1}{2} \right\rangle_\lambda = \frac{1}{3}\left(O^\mu\left(\frac{1}{2}, \frac{1}{2}\right) + 2O^\mu\left(-\frac{1}{2}, -\frac{1}{2}\right) \right)$$
$${}_\lambda\left\langle \frac{1}{2}, s_z^\Lambda = -\frac{1}{2} | \hat{O}^\mu | \frac{1}{2}, s_z^p = \frac{1}{2} \right\rangle_\lambda = \frac{1}{3} O^\mu\left(-\frac{1}{2}, \frac{1}{2}\right),$$

$$O^\mu\left(s_z^s, s_z^u\right) = \bar{u}_s\left(\mathbf{q}_s,\ s_z^s\right) \gamma^\nu \left(1-\gamma^5\right) u_u\left(\mathbf{q}_u,\ s_z^u\right)$$

W-强子对的顶点计算



基于夸克层次的计算

$$T_2^{\nu}(\mathbf{p}_w, s_z^{Q_1}, s_z^{Q_2}) = \int d\mathbf{p}_a d\mathbf{p}_b d\mathbf{p}_{q_1} d\mathbf{p}_{q_2} \delta_{(\mathbf{p}_a+\mathbf{p}_b+\mathbf{p}_{q_1})} \delta_{(\mathbf{p}_{q_2}-\mathbf{p}_{q_1}-\mathbf{p}_w)} \times \sqrt{\frac{G_F m_W}{\sqrt{2}}} |v_{q_1 q_2}|$$
$$\times \sum_{s_z^{q2},\, s_z^{q1}} \langle X^{Q_2},\ s_z^{Q_2},\ \Phi^{Q_2} | \chi^{+}_{q2,\, s_z^{q2}} \chi_{q1,\, s_z^{q1}} | X^{Q_1},\ s_z^{Q_1},\ \Phi^{Q_1} \rangle$$
$$\times \bar{u}_{q_2}(\mathbf{p}_{q_2},\ s_z^{q_2}) \gamma^{\nu} (1-\gamma^5) u_{q_1}(\mathbf{p}_{q_1},\ s_z^{q_1}),$$

$$|N(939)\rangle = 0.90|N_8^2 S_s\rangle + 0.34|N_8^2 S_s'\rangle - 0.27|N_8^2 S_M\rangle,$$
$$|\Lambda(1115)\rangle = 0.93|\Lambda_8^2 S_s\rangle + 0.30|\Lambda_8^2 S_s'\rangle - 0.20|\Lambda_8^2 S_M\rangle,$$

$$\left|B_8^2 S_s, \frac{1}{2}^{+}\right\rangle = \frac{1}{\sqrt{2}} \left(|B\rangle_\lambda \left|\frac{1}{2}, s_z\right\rangle_\lambda + |B\rangle_\rho \left|\frac{1}{2}, s_z\right\rangle_\rho \right) \Phi_{000}(\mathbf{q}_\lambda, \mathbf{q}_\rho)$$

味道波函数部分

$${}_\lambda\langle \Lambda | \chi_s^{+} \chi_u | p \rangle_\lambda = 0,$$
$${}_\lambda\langle \Lambda | \chi_s^{+} \chi_u | p \rangle_\rho = 0,$$
$${}_\rho\langle \Lambda | \chi_s^{+} \chi_u | p \rangle_\lambda = 0,$$
$${}_\rho\langle \Lambda | \chi_s^{+} \chi_u | p \rangle_\rho = \frac{\sqrt{6}}{3}.$$

自旋波函数部分

$${}_\rho\left\langle \frac{1}{2}, s_z^{\Lambda} | \hat{O}^{\mu} | \frac{1}{2}, s_z^{p} \right\rangle_\rho = O^{\mu}(s_z^{\Lambda}, s_z^{p}),$$
$${}_\rho\left\langle \frac{1}{2}, s_z^{\Lambda} | \hat{O}^{\mu} | \frac{1}{2}, s_z^{p} \right\rangle_\lambda = 0,$$
$${}_\lambda\left\langle \frac{1}{2}, s_z^{\Lambda} | \hat{O}^{\mu} | \frac{1}{2}, s_z^{p} \right\rangle_\rho = 0,$$
$${}_\lambda\left\langle \frac{1}{2}, s_z^{\Lambda} = \frac{1}{2} | \hat{O}^{\mu} | \frac{1}{2}, s_z^{p} = \frac{1}{2} \right\rangle_\lambda = \frac{1}{3}\left(O^{\mu}\left(\frac{1}{2}, \frac{1}{2}\right) + 2O^{\mu}\left(-\frac{1}{2}, -\frac{1}{2}\right) \right)$$
$${}_\lambda\left\langle \frac{1}{2}, s_z^{\Lambda} = -\frac{1}{2} | \hat{O}^{\mu} | \frac{1}{2}, s_z^{p} = \frac{1}{2} \right\rangle_\lambda = \frac{1}{3} O^{\mu}\left(-\frac{1}{2}, \frac{1}{2}\right),$$

$$O^{\mu}(s_z^s, s_z^u) = \bar{u}_s(\mathbf{q}_s,\ s_z^s) \gamma^{\nu} \left(1-\gamma^5\right) u_u(\mathbf{q}_u,\ s_z^u)$$

结合空间波函数部分

$$T^{\mu}_{2\ \Lambda-p-W}(s_z^{\Lambda}, s_z^{p}) = \int -\frac{9}{2} d\mathbf{q}_u d\mathbf{q}_\rho \sqrt{\left(\frac{G_F m_W^2}{\sqrt{2}}\right)} |v_{us}|$$
$$\times \left\{ \left[\frac{0.90}{\sqrt{2}} \Phi_{000}(\mathbf{q}_\lambda^{p}, \mathbf{q}_\rho) + \frac{0.34}{\sqrt{2}} \Phi^{s}_{200}(\mathbf{q}_\lambda^{p}, \mathbf{q}_\rho) + \frac{0.27}{2} \Phi^{\lambda}_{200}(\mathbf{q}_\lambda^{p}, \mathbf{q}_\rho) \right] \right.$$
$$\times \left[\frac{0.93}{\sqrt{2}} \Phi_{000}(\mathbf{q}_\lambda^{\Lambda}, \mathbf{q}_\rho) + \frac{0.30}{\sqrt{2}} \Phi^{s}_{200}(\mathbf{q}_\lambda^{\Lambda}, \mathbf{q}_\rho) + \frac{0.20}{2} \Phi^{\lambda}_{200}(\mathbf{q}_\lambda^{\Lambda}, \mathbf{q}_\rho) \right]$$
$$\times {}_\rho\langle \frac{1}{2}, s_z^{\Lambda} | \hat{O}^{\nu} | \frac{1}{2}, s_z^{p} \rangle_\rho$$
$$\left. + \frac{0.27}{2} \frac{0.20}{2} \Phi^{\lambda}_{200}(\mathbf{q}_\lambda^{p}, \mathbf{q}_\rho) \Phi^{\lambda}_{200}(\mathbf{q}_\lambda^{\Lambda}, \mathbf{q}_\rho)_\lambda \langle \frac{1}{2}, s_z^{\Lambda} | \hat{O}^{\nu} | \frac{1}{2}, s_z^{p} \rangle_\lambda \right\}$$

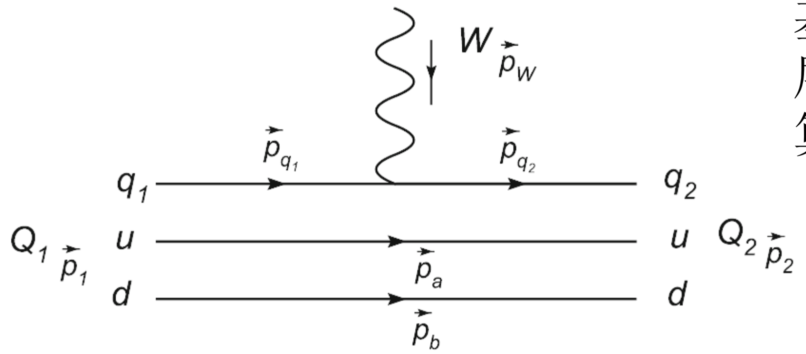
$$\mathbf{p}_{1\rho} = \frac{\mathbf{p}_a - \mathbf{p}_b}{\sqrt{2}},$$

$$\mathbf{p}_{1\lambda} = \frac{\mathbf{p}_a + \mathbf{p}_b - 2\mathbf{p}_{q_1}}{\sqrt{6}} = \frac{-3\mathbf{p}_{q_1}}{\sqrt{6}},$$

$$\mathbf{p}_{2\rho} = \frac{\mathbf{p}_a - \mathbf{p}_b}{\sqrt{2}},$$

$$\mathbf{p}_{2\lambda} = \frac{\mathbf{p}_a + \mathbf{p}_b - 2\mathbf{p}_{q_2}}{\sqrt{6}} = \frac{-3\mathbf{p}_{q_1} - 2\mathbf{p}_w}{\sqrt{6}}$$

W-强子对的顶点计算



基于夸克层次的计算

$$T_2^\nu(\mathbf{p}_w, s_z^{Q_1}, s_z^{Q_2}) = \int d\mathbf{p}_a d\mathbf{p}_b d\mathbf{p}_{q_1} d\mathbf{p}_{q_2} \delta_{(\mathbf{p}_a+\mathbf{p}_b+\mathbf{p}_{q_1})} \delta_{(\mathbf{p}_{q_2}-\mathbf{p}_{q_1}-\mathbf{p}_w)} \times \sqrt{\frac{G_F m_W}{\sqrt{2}}} |v_{q_1 q_2}|$$
$$\times \sum_{s_z^{q_2},\, s_z^{q_1}} \langle X^{Q_2},\ s_z^{Q_2},\ \Phi^{Q_2} | \chi^+_{q_2,\, s_z^{q_2}} \chi_{q_1,\, s_z^{q_1}} | X^{Q_1},\ s_z^{Q_1},\ \Phi^{Q_1} \rangle$$
$$\times \bar{u}_{q_2}(\mathbf{p}_{q_2},\ s_z^{q_2}) \gamma^\nu (1-\gamma^5) u_{q_1}(\mathbf{p}_{q_1},\ s_z^{q_1}),$$

$$|N(939)\rangle = 0.90|N_8^2 S_s\rangle + 0.34|N_8^2 S_s'\rangle - 0.27|N_8^2 S_M\rangle,$$
$$|\Lambda(1115)\rangle = 0.93|\Lambda_8^2 S_s\rangle + 0.30|\Lambda_8^2 S_s'\rangle - 0.20|\Lambda_8^2 S_M\rangle,$$

$$\left|B_8^2 S_s, \frac{1}{2}^+\right\rangle = \frac{1}{\sqrt{2}}\left(|B\rangle_\lambda \left|\frac{1}{2}, s_z\right\rangle_\lambda + |B\rangle_\rho \left|\frac{1}{2}, s_z\right\rangle_\rho\right) \Phi_{000}(\mathbf{q}_\lambda, \mathbf{q}_\rho)$$

味道波函数部分

$${}_\lambda\langle \Lambda | \chi_s^+ \chi_u | p \rangle_\lambda = 0,$$
$${}_\lambda\langle \Lambda | \chi_s^+ \chi_u | p \rangle_\rho = 0,$$
$${}_\rho\langle \Lambda | \chi_s^+ \chi_u | p \rangle_\lambda = 0,$$
$${}_\rho\langle \Lambda | \chi_s^+ \chi_u | p \rangle_\rho = \frac{\sqrt{6}}{3}.$$

自旋波函数部分

$${}_\rho\left\langle \frac{1}{2}, s_z^\Lambda | \hat{O}^\mu | \frac{1}{2}, s_z^p \right\rangle_\rho = O^\mu(s_z^\Lambda, s_z^p),$$
$${}_\rho\left\langle \frac{1}{2}, s_z^\Lambda | \hat{O}^\mu | \frac{1}{2}, s_z^p \right\rangle_\lambda = 0,$$
$${}_\lambda\left\langle \frac{1}{2}, s_z^\Lambda | \hat{O}^\mu | \frac{1}{2}, s_z^p \right\rangle_\rho = 0,$$
$${}_\lambda\left\langle \frac{1}{2}, s_z^\Lambda = \frac{1}{2} | \hat{O}^\mu | \frac{1}{2}, s_z^p = \frac{1}{2} \right\rangle_\lambda = \frac{1}{3}\left(O^\mu\left(\frac{1}{2}, \frac{1}{2}\right) + 2O^\mu\left(-\frac{1}{2}, -\frac{1}{2}\right)\right)$$
$${}_\lambda\left\langle \frac{1}{2}, s_z^\Lambda = -\frac{1}{2} | \hat{O}^\mu | \frac{1}{2}, s_z^p = \frac{1}{2} \right\rangle_\lambda = \frac{1}{3} O^\mu\left(-\frac{1}{2}, \frac{1}{2}\right),$$

$$O^\mu\left(s_z^s, s_z^u\right) = \bar{u}_s\left(\mathbf{q}_s,\ s_z^s\right) \gamma^\nu \left(1-\gamma^5\right) u_u\left(\mathbf{q}_u,\ s_z^u\right)$$

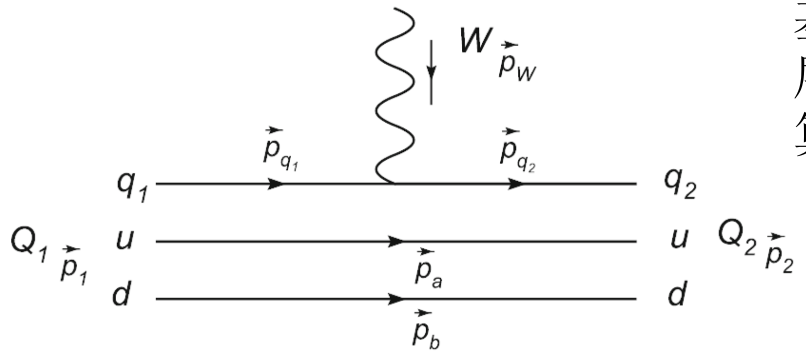
结合空间波函数部分

$$T^\mu_{2\ \Lambda-p-W}(s_z^\Lambda, s_z^p) = \int -\frac{9}{2} d\mathbf{q}_u d\mathbf{q}_\rho \sqrt{\left(\frac{G_F m_W^2}{\sqrt{2}}\right)} |v_{us}|$$
$$\times \left\{ \left[\frac{0.90}{\sqrt{2}} \Phi_{000}(\mathbf{q}_\lambda^p, \mathbf{q}_\rho) + \frac{0.34}{\sqrt{2}} \Phi^s_{200}(\mathbf{q}_\lambda^p, \mathbf{q}_\rho) + \frac{0.27}{2} \Phi^\lambda_{200}(\mathbf{q}_\lambda^p, \mathbf{q}_\rho)\right]\right.$$
$$\times \left[\frac{0.93}{\sqrt{2}} \Phi_{000}(\mathbf{q}_\lambda^\Lambda, \mathbf{q}_\rho) + \frac{0.30}{\sqrt{2}} \Phi^s_{200}(\mathbf{q}_\lambda^\Lambda, \mathbf{q}_\rho) + \frac{0.20}{2} \Phi^\lambda_{200}(\mathbf{q}_\lambda^\Lambda, \mathbf{q}_\rho)\right]$$
$$\times {}_\rho\langle \frac{1}{2}, s_z^\Lambda | \hat{O}^\nu | \frac{1}{2}, s_z^p \rangle_\rho$$
$$\left. + \frac{0.27}{2} \frac{0.20}{2} \Phi^\lambda_{200}(\mathbf{q}_\lambda^p, \mathbf{q}_\rho) \Phi^\lambda_{200}(\mathbf{q}_\lambda^\Lambda, \mathbf{q}_\rho)_\lambda \langle \frac{1}{2}, s_z^\Lambda | \hat{O}^\nu | \frac{1}{2}, s_z^p \rangle_\lambda \right\}$$

$$\mathbf{q}_\lambda^p = -3\mathbf{q}_u/\sqrt{6}, \qquad \mathbf{q}_\lambda^\Lambda = -(3\mathbf{q}_u + 2\mathbf{q}_W)/\sqrt{6}.$$

$$\mathbf{p}_{1\rho} = \frac{\mathbf{p}_a - \mathbf{p}_b}{\sqrt{2}},$$
$$\mathbf{p}_{1\lambda} = \frac{\mathbf{p}_a + \mathbf{p}_b - 2\mathbf{p}_{q_1}}{\sqrt{6}} = \frac{-3\mathbf{p}_{q_1}}{\sqrt{6}},$$
$$\mathbf{p}_{2\rho} = \frac{\mathbf{p}_a - \mathbf{p}_b}{\sqrt{2}},$$
$$\mathbf{p}_{2\lambda} = \frac{\mathbf{p}_a + \mathbf{p}_b - 2\mathbf{p}_{q_2}}{\sqrt{6}} = \frac{-3\mathbf{p}_{q_1} - 2\mathbf{p}_w}{\sqrt{6}}$$

W-强子对的顶点计算



基于夸克层次的计算

$$T_2^{\nu}(\mathbf{p}_w, s_z^{Q_1}, s_z^{Q_2}) = \int d\mathbf{p}_a d\mathbf{p}_b d\mathbf{p}_{q_1} d\mathbf{p}_{q_2} \delta_{(\mathbf{p}_a+\mathbf{p}_b+\mathbf{p}_{q_1})} \delta_{(\mathbf{p}_{q_2}-\mathbf{p}_{q_1}-\mathbf{p}_w)} \times \sqrt{\frac{G_F m_W}{\sqrt{2}}} |v_{q_1 q_2}|$$
$$\times \sum_{s_z^{q_2},\, s_z^{q_1}} \langle X^{Q_2},\ s_z^{Q_2},\ \Phi^{Q_2} | \chi^+_{q_2,\, s_z^{q_2}} \chi_{q_1,\, s_z^{q_1}} | X^{Q_1},\ s_z^{Q_1},\ \Phi^{Q_1} \rangle$$
$$\times \bar{u}_{q_2}(\mathbf{p}_{q_2},\ s_z^{q_2}) \gamma^{\nu} (1-\gamma^5) u_{q_1}(\mathbf{p}_{q_1},\ s_z^{q_1}),$$

$$|N(939)\rangle = 0.90|N_8^2 S_s\rangle + 0.34|N_8^2 S_s'\rangle - 0.27|N_8^2 S_M\rangle,$$
$$|\Lambda(1115)\rangle = 0.93|\Lambda_8^2 S_s\rangle + 0.30|\Lambda_8^2 S_s'\rangle - 0.20|\Lambda_8^2 S_M\rangle,$$

$$\left|B_8^2 S_s, \frac{1}{2}^+\right\rangle = \frac{1}{\sqrt{2}}\left(|B\rangle_\lambda \left|\frac{1}{2}, s_z\right\rangle_\lambda + |B\rangle_\rho \left|\frac{1}{2}, s_z\right\rangle_\rho\right) \Phi_{000}(\mathbf{q}_\lambda, \mathbf{q}_\rho)$$

味道波函数部分

$${}_\lambda\langle \Lambda | \chi_s^+ \chi_u | p \rangle_\lambda = 0,$$
$${}_\lambda\langle \Lambda | \chi_s^+ \chi_u | p \rangle_\rho = 0,$$
$${}_\rho\langle \Lambda | \chi_s^+ \chi_u | p \rangle_\lambda = 0,$$
$${}_\rho\langle \Lambda | \chi_s^+ \chi_u | p \rangle_\rho = \frac{\sqrt{6}}{3}.$$

自旋波函数部分

$${}_\rho\left\langle \frac{1}{2}, s_z^\Lambda | \hat{O}^\mu | \frac{1}{2}, s_z^p \right\rangle_\rho = O^\mu(s_z^\Lambda, s_z^p),$$
$${}_\rho\left\langle \frac{1}{2}, s_z^\Lambda | \hat{O}^\mu | \frac{1}{2}, s_z^p \right\rangle_\lambda = 0,$$
$${}_\lambda\left\langle \frac{1}{2}, s_z^\Lambda | \hat{O}^\mu | \frac{1}{2}, s_z^p \right\rangle_\rho = 0,$$
$${}_\lambda\left\langle \frac{1}{2}, s_z^\Lambda = \frac{1}{2} | \hat{O}^\mu | \frac{1}{2}, s_z^p = \frac{1}{2} \right\rangle_\lambda = \frac{1}{3}\left(O^\mu\left(\frac{1}{2}, \frac{1}{2}\right) + 2O^\mu\left(-\frac{1}{2}, -\frac{1}{2}\right)\right)$$
$${}_\lambda\left\langle \frac{1}{2}, s_z^\Lambda = -\frac{1}{2} | \hat{O}^\mu | \frac{1}{2}, s_z^p = \frac{1}{2} \right\rangle_\lambda = \frac{1}{3}O^\mu\left(-\frac{1}{2}, \frac{1}{2}\right),$$

$$O^\mu\left(s_z^s, s_z^u\right) = \bar{u}_s\left(\mathbf{q}_s,\ s_z^s\right) \gamma^\nu \left(1-\gamma^5\right) u_u\left(\mathbf{q}_u,\ s_z^u\right)$$

结合空间波函数部分

$$T^{\mu}_{2\,\Lambda-p-W}(s_z^\Lambda, s_z^p) = \int -\frac{9}{2} d\mathbf{q}_u d\mathbf{q}_\rho \sqrt{\left(\frac{G_F m_W^2}{\sqrt{2}}\right)} |v_{us}|$$
$$\times \left\{\left[\frac{0.90}{\sqrt{2}}\Phi_{000}(\mathbf{q}_\lambda^p, \mathbf{q}_\rho) + \frac{0.34}{\sqrt{2}}\Phi_{200}^s(\mathbf{q}_\lambda^p, \mathbf{q}_\rho) + \frac{0.27}{2}\Phi_{200}^\lambda(\mathbf{q}_\lambda^p, \mathbf{q}_\rho)\right]\right.$$
$$\times \left[\frac{0.93}{\sqrt{2}}\Phi_{000}(\mathbf{q}_\lambda^\Lambda, \mathbf{q}_\rho) + \frac{0.30}{\sqrt{2}}\Phi_{200}^s(\mathbf{q}_\lambda^\Lambda, \mathbf{q}_\rho) + \frac{0.20}{2}\Phi_{200}^\lambda(\mathbf{q}_\lambda^\Lambda, \mathbf{q}_\rho)\right]$$
$$\times {}_\rho\langle \frac{1}{2}, s_z^\Lambda | \hat{O}^\nu | \frac{1}{2}, s_z^p \rangle_\rho$$
$$\left. + \frac{0.27}{2}\frac{0.20}{2}\Phi_{200}^\lambda(\mathbf{q}_\lambda^p, \mathbf{q}_\rho)\Phi_{200}^\lambda(\mathbf{q}_\lambda^\Lambda, \mathbf{q}_\rho)_\lambda \langle \frac{1}{2}, s_z^\Lambda | \hat{O}^\nu | \frac{1}{2}, s_z^p \rangle_\lambda \right\}$$

$$\mathbf{q}_\lambda^p = -3\mathbf{q}_u/\sqrt{6}. \qquad \mathbf{q}_\lambda^\Lambda = -(3\mathbf{q}_u + 2\mathbf{q}_W)/\sqrt{6}.$$

超子弱衰变计算

The branching ratio ($\times 10^{-4}$) of $\Lambda(1115)$		
Model	$\bar{\nu}_e + e^- + p$	$\bar{\nu}_\mu + \mu^- + p$
EXP-A	8.18	1.36
EXP-B	8.25	1.38
R3QM	9.31	1.55
NR3QM-full	10.7	1.82
NR3QM-single	11.8	1.95
Experimental data [14]	8.32 ± 0.14	1.57 ± 0.35
The branching ratio ($\times 10^{-4}$) of $\Sigma^0(1193)$		
Model	$\bar{\nu}_e + e^- + p$	$\bar{\nu}_\mu + \mu^- + p$
EXP	22.43	10.32
R3QM	20.10	9.35
NR3QM-full	18.82	8.82
NR3QM-single	23.83	10.80
Experimental data [14]	-	-
The branching ratio ($\times 10^{-4}$) of $\Sigma^-(1193)$		
Model	$\bar{\nu}_e + e^- + n$	$\bar{\nu}_\mu + \mu^- + n$
EXP	9.58	4.51
R3QM	9.30	4.06
NR3QM-full	8.16	3.95
NR3QM-single	10.35	4.85
Experimental data [14]	10.17 ± 0.34	4.5 ± 0.4

都有比较准确的估计

超子弱衰变计算

The branching ratio ($\times 10^{-4}$) of $\Lambda(1115)$

Model	$\bar{\nu}_e + e^- + p$	$\bar{\nu}_\mu + \mu^- + p$	
EXP-A	8.18	1.36	**0.166**
EXP-B	8.25	1.38	**0.167**
R3QM	9.31	1.55	**0.166**
NR3QM-full	10.7	1.82	**0.170**
NR3QM-single	11.8	1.95	**0.165**
Experimental data [14]	8.32 ± 0.14	1.57 ± 0.35	

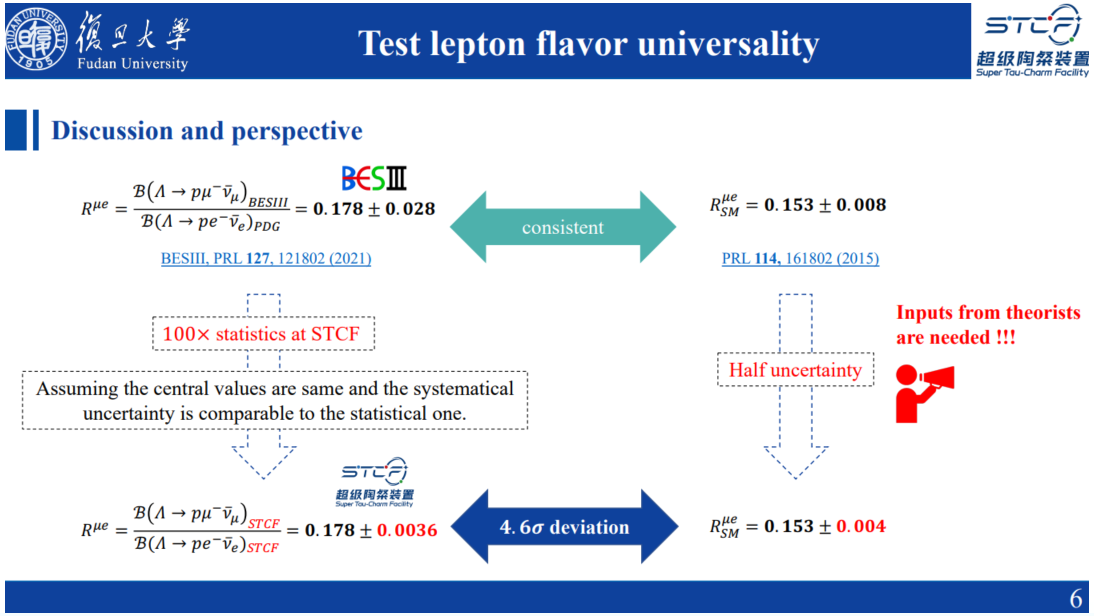
The branching ratio ($\times 10^{-14}$) of $\Sigma^0(1193)$

Model	$\bar{\nu}_e + e^- + p$	$\bar{\nu}_\mu + \mu^- + p$
EXP	22.43	10.32
R3QM	20.10	9.35
NR3QM-full	18.82	8.82
NR3QM-single	23.83	10.80
Experimental data [14]	-	-

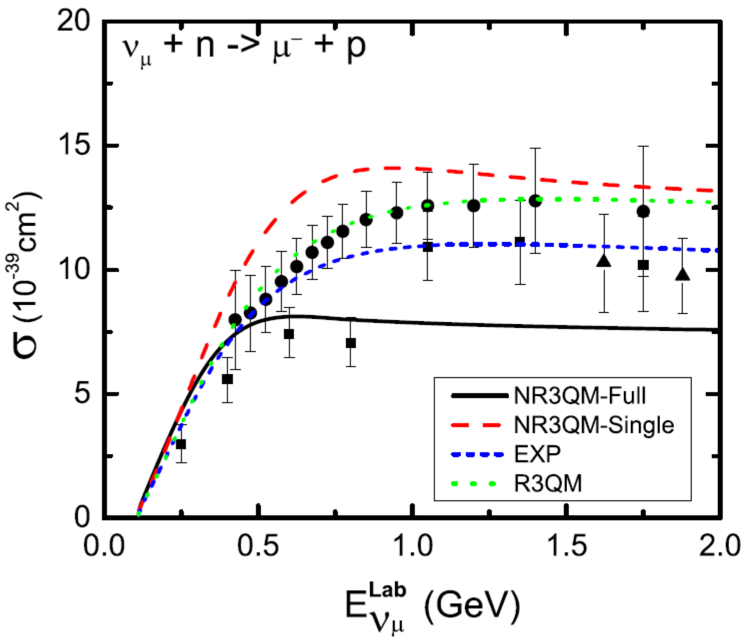
The branching ratio ($\times 10^{-4}$) of $\Sigma^-(1193)$

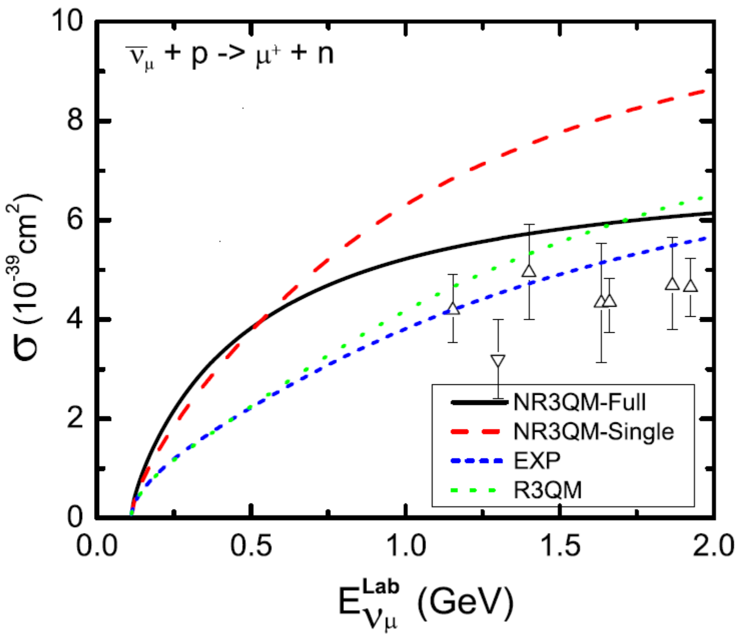
Model	$\bar{\nu}_e + e^- + n$	$\bar{\nu}_\mu + \mu^- + n$
EXP	9.58	4.51
R3QM	9.30	4.06
NR3QM-full	8.16	3.95
NR3QM-single	10.35	4.85
Experimental data [14]	10.17 ± 0.34	4.5 ± 0.4

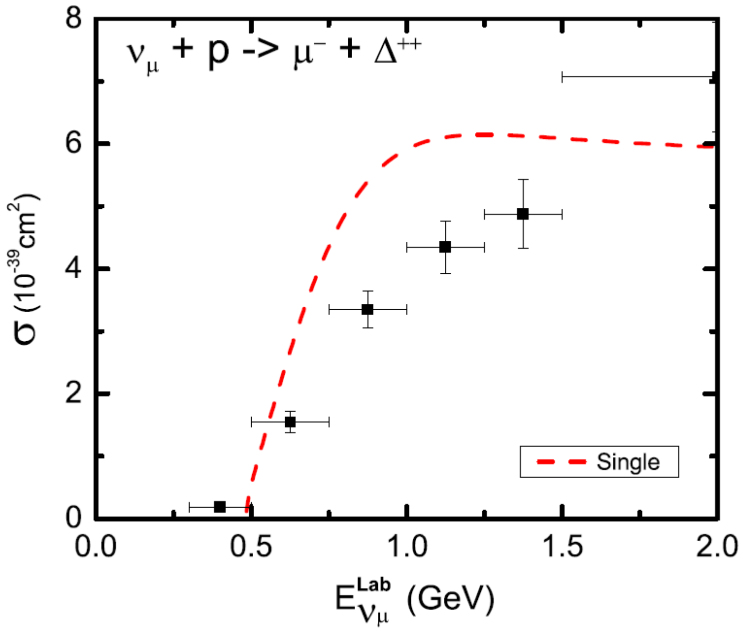
都有比较准确的估计

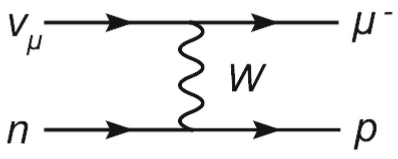


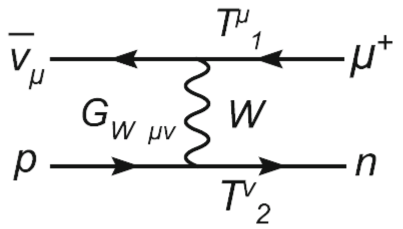
中微子束流产生核子估计

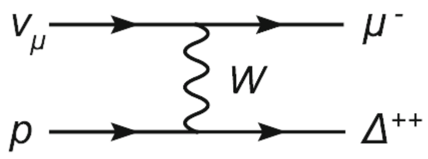




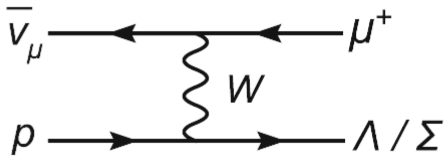


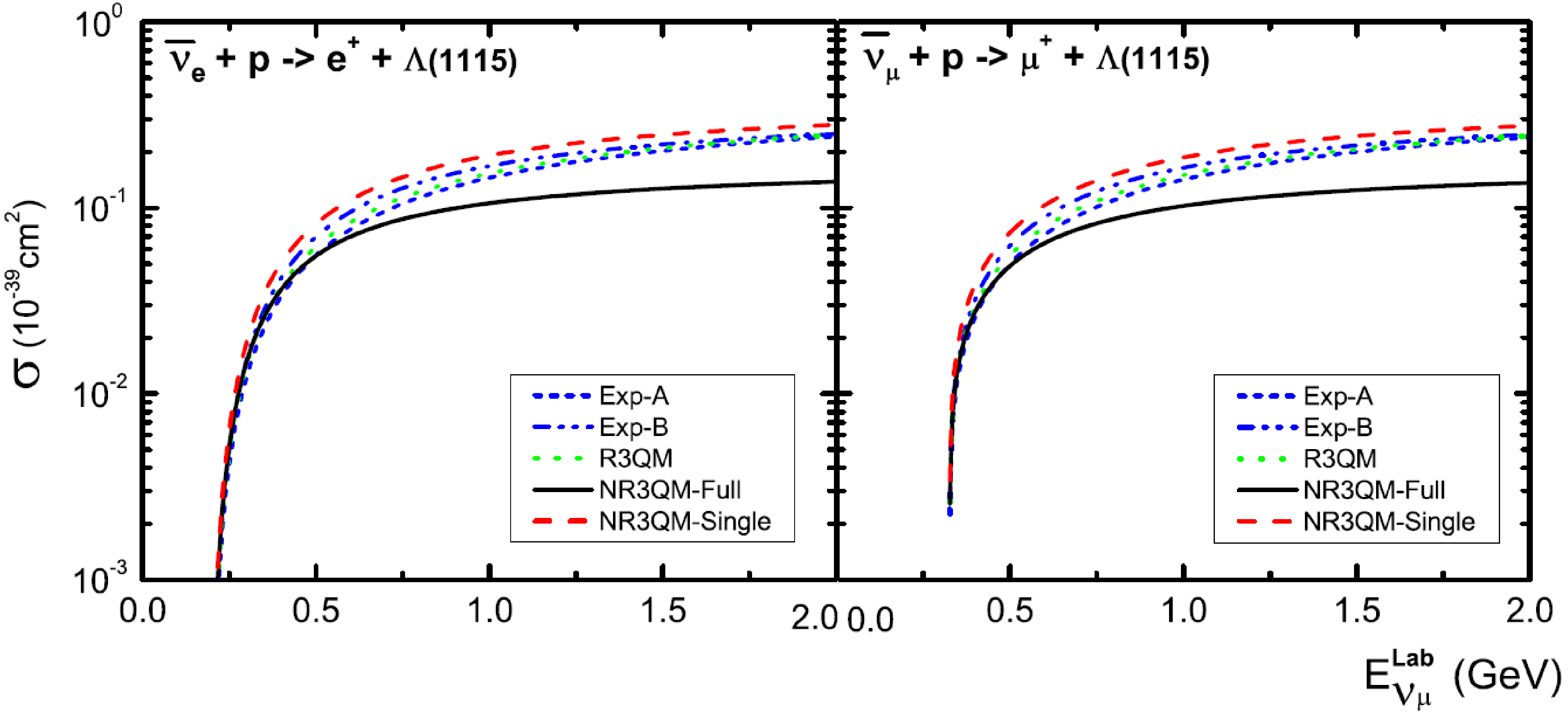






中微子束流产生超子估计





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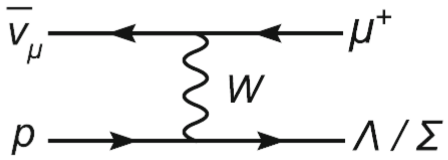

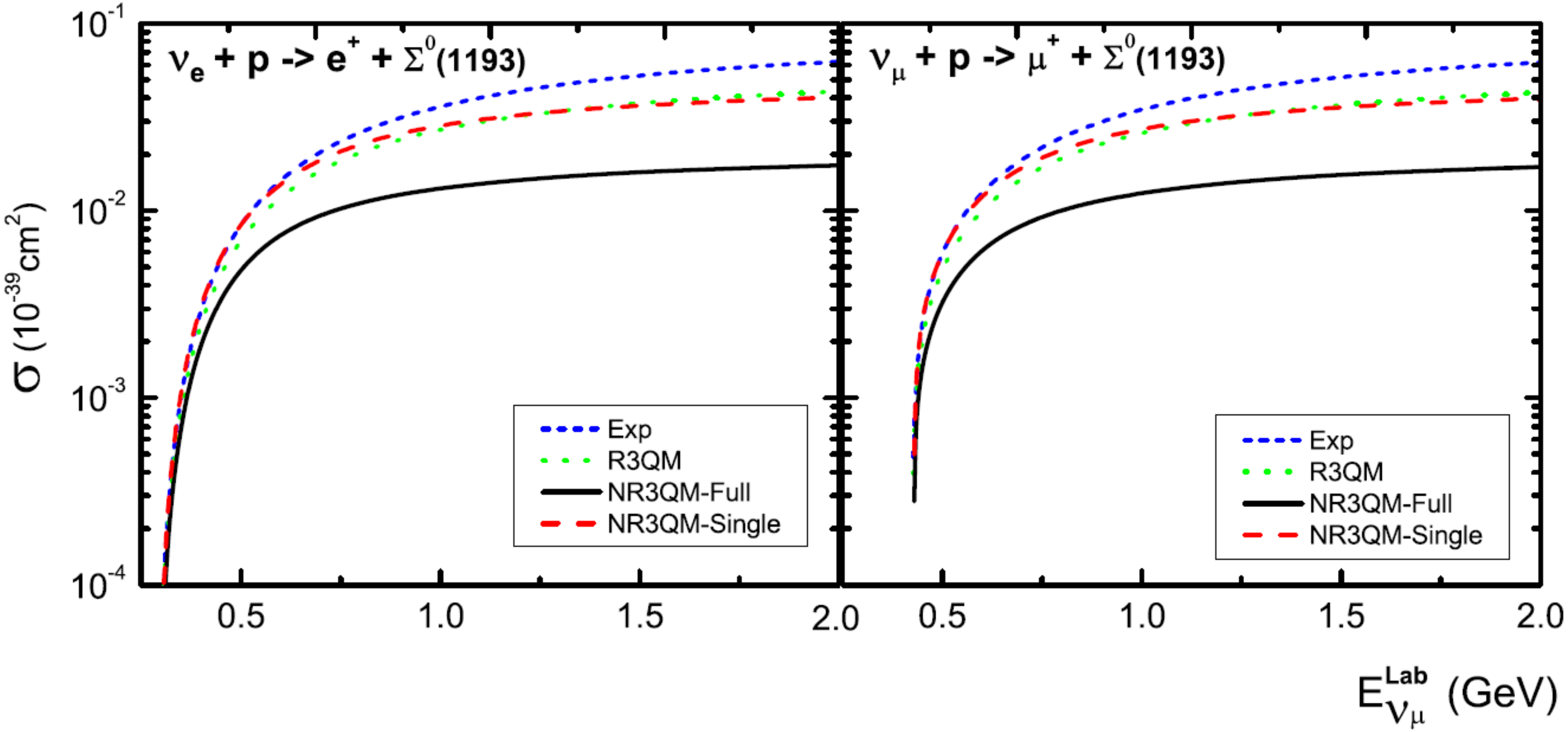

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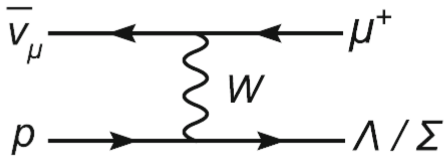
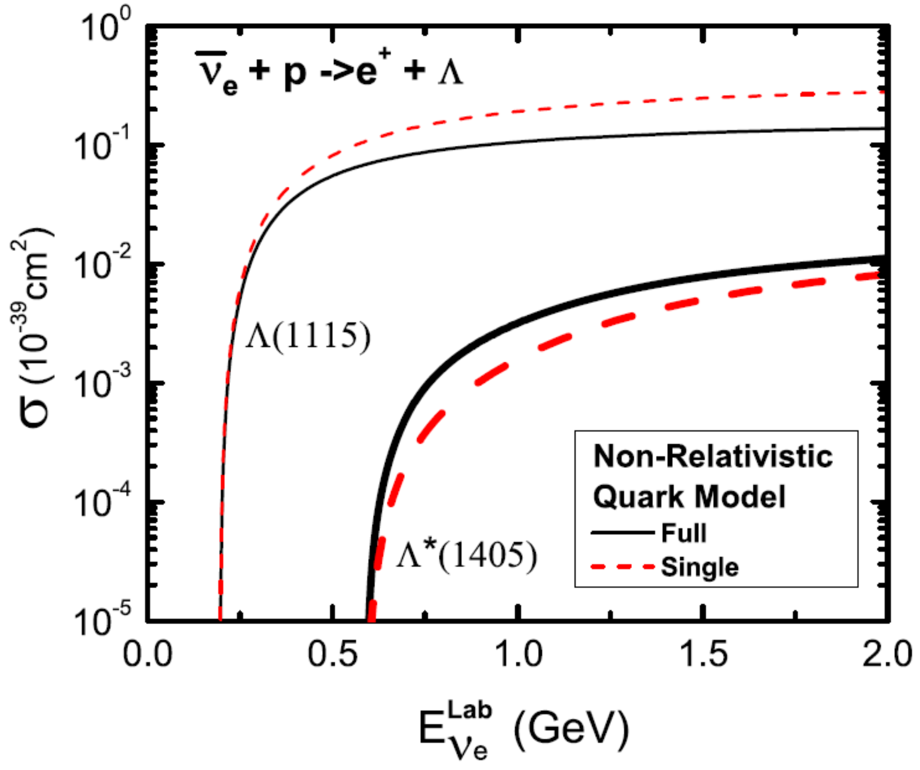
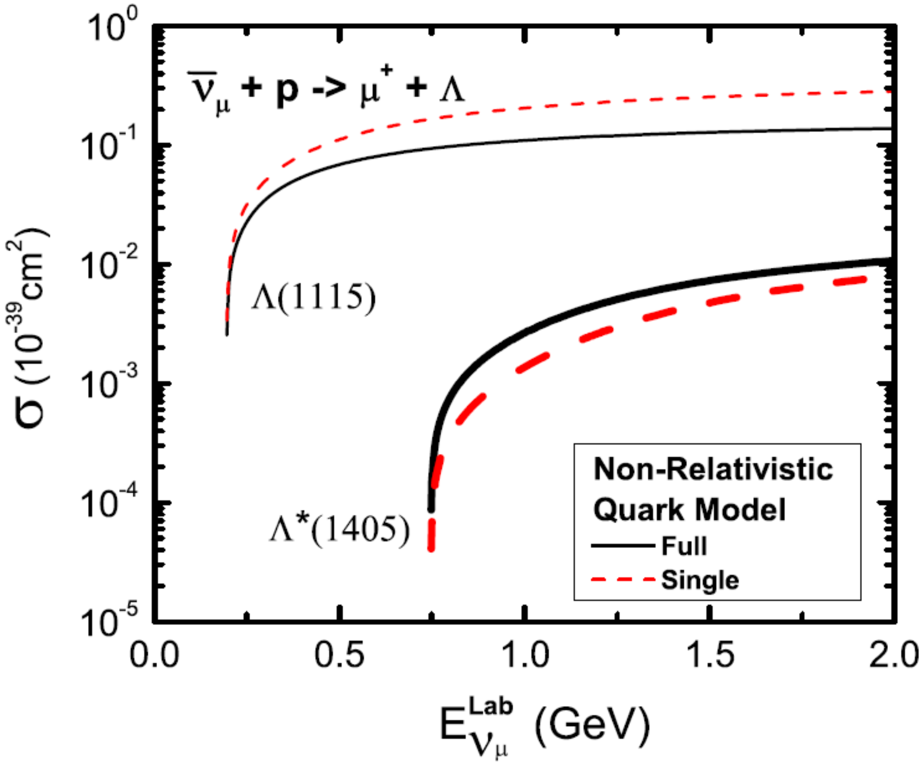
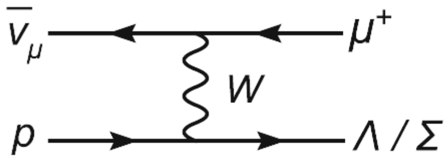
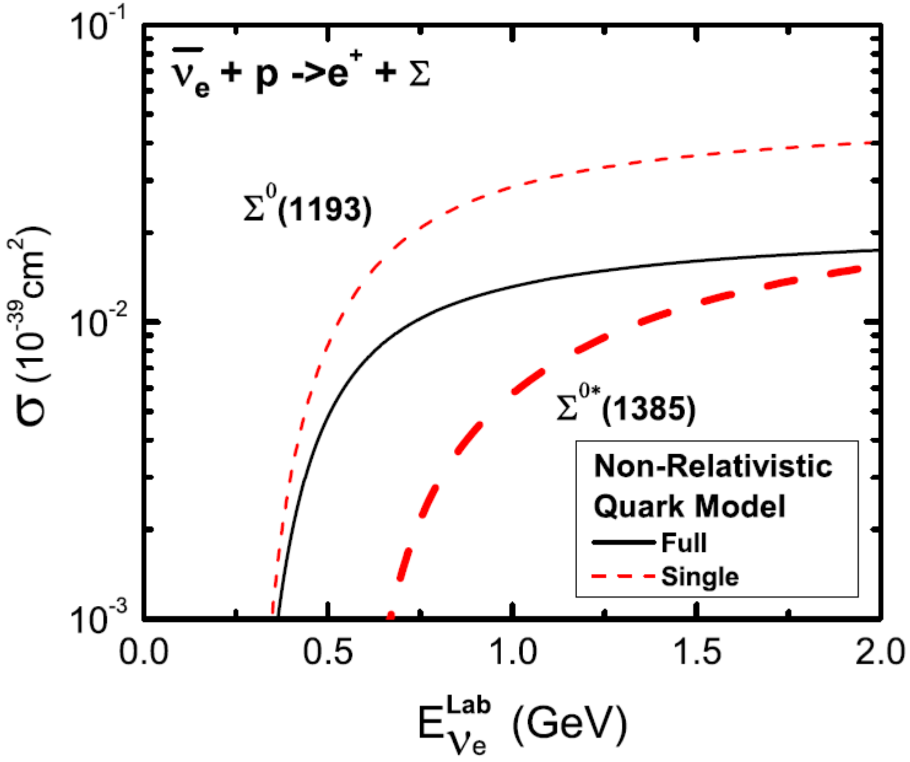


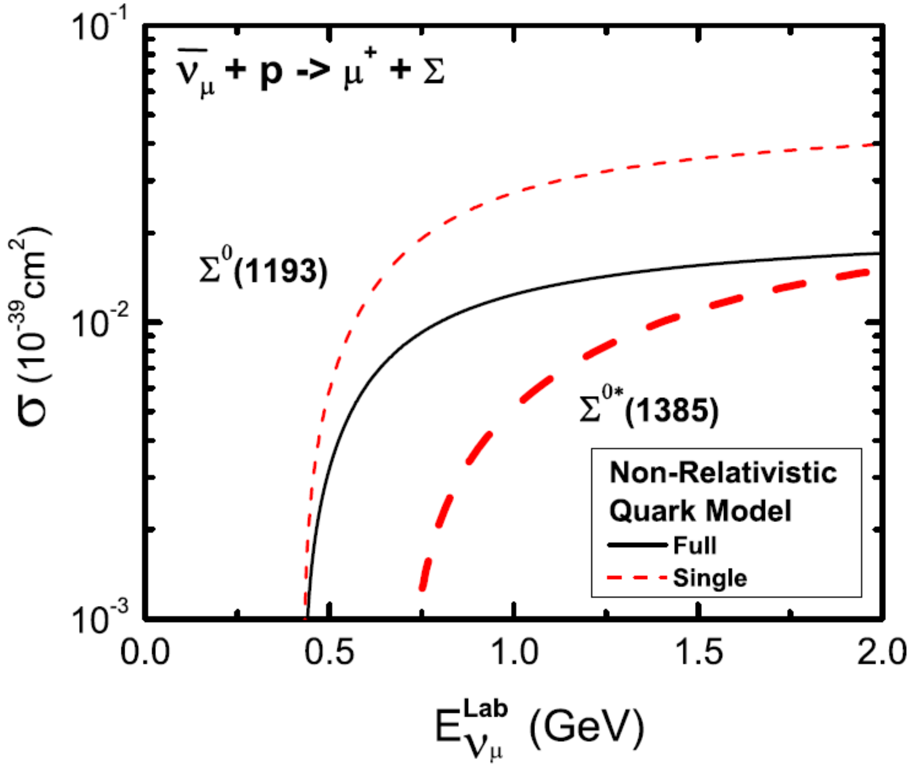




中微子束流产生超子估计







小结

利用夸克模型估计了中微子束流产生超子。

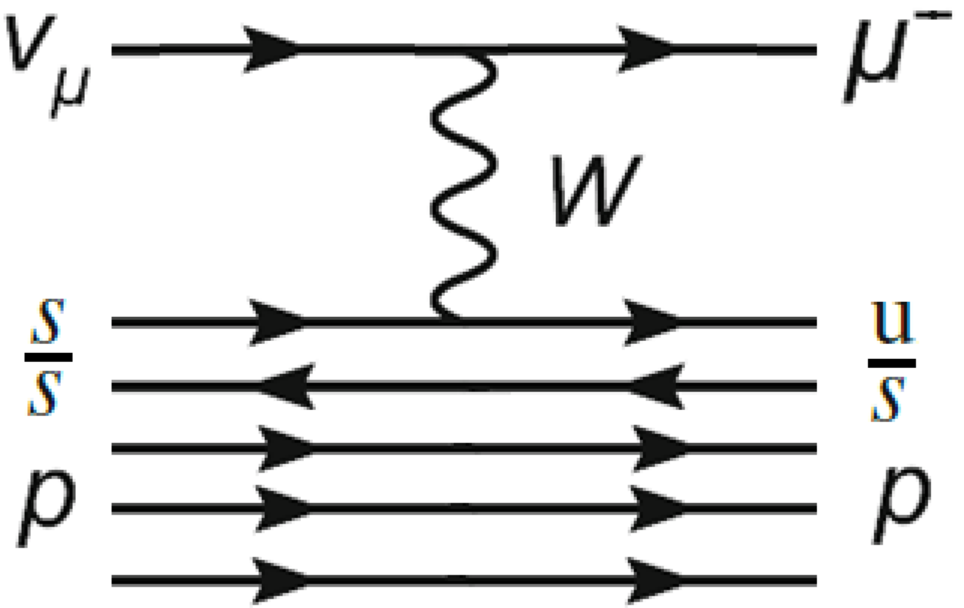
期待相关实验的检验，并且我们相信现在的理论估计是非常粗糙的，只是在量级上估计，亟待实验数据的输入能够鉴别参数和约束更多的模型参数

展望

利用中微子束流估计核子内部的$s\bar{s}/c\bar{c}$成分。

------邹冰松老师 idea

举例而言



HIAF轻强子谱

COSY能区、亮度及多个探测器，都有局限性。
HIAF + CEE 在能区、亮度和探测器等方面全方位超过COSY，在重子谱研究方面大有可为。

pp → $pK^+\Lambda$, $nK^+\Sigma^+$, $pK^+\Sigma^0$, $Ks\Sigma^+p$, $pp\phi$, $pp\eta$, $pp\eta'$, ppK^+K^-,
pnK^+Ks, $p\Lambda Ks\ \pi^+$, $p\Lambda K^+\eta$, $p\Lambda K^+\phi$, $p\Xi^-K^+K^+$, ……

→ strange partners of P_c and P_{cs} states

+ more reliable input for studying K production in HIC

另外 pp → n $K^+\Sigma^+$ 为寻找与ρ^+p及 $K^+\Sigma^+$耦合强的“失踪”的 Δ^{*++}重子激发态，完善(uuu) 重子谱，可起到国际上独一无二的作用.

目前Δ^{*++}(uuu) 重子谱只有 12 个确立的成员

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

------邹冰松老师PPT

谢谢

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