DYNAMICALLY GENERARTED RESONANCES IN THE VECTOR MESON- BARYON SYSTEMS

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in collaboration with

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"New hadrons" workshop, Riken, Japan.

March 1, 2011

Dynamical generation of Baryon resonances from Meson-Baryon interaction

- Hadron dynamics is important at the intermediate energies.

- Many resonances have been found to get generated from hadron-hadron interaction* (also in meson-meson-baryon and three-meson systems**).

******Some Refs:* *J.A.Oller and E.Oset, NPA620: 438-456,1997,Kaiser EPJ.A3:307-309,1998, L. Roca, E. Oset and J. Singh, Phys. Rev. D 72 (2005) 014002, E. E. Kolomeitsev and M. F. M. Lutz, Phys. Lett. B 585 (2004) 243, S. Sarkar, E. Oset and M. J. Vicente Vacas, Nucl. Phys. A 750 (2005) 294. etc.*

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- Pseudoscalar-baryon systems: well explained in terms of Weinberg Tomozawa interaction + low energy theorems

Vector meson-Baryon interaction has been studied for example by

(Based on hidden gauge symmetry {Bando. et. al. 1985}.)

- E. Oset and A. Ramos *(EPJA 44, 445 (2010)) -----> WT (like) interaction*

I, S	Theory			PDG data				
	pole position	real axis mass	width	name	J^P	status	mass	width
$1/2, 0$	—	1696	92	$N(1650)$	$1/2^-$	$\star\star\star\star$	1645-1670	145-185
				$N(1700)$	$3/2^-$	$\star\star\star$	1650-1750	50-150
	$1977 + i53$	1972	64	$N(2080)$	$3/2^-$	$\star\star$	≈ 2080	180-450
				$N(2090)$	$1/2^-$	$\star$	≈ 2090	100-400
$0, -1$	$1784 + i4$	1783	9	$\Lambda(1690)$	$3/2^-$	$\star\star\star\star$	1685-1695	50-70
				$\Lambda(1800)$	$1/2^-$	$\star\star\star$	1720-1850	200-400
	$1907 + i70$	1900	54	$\Lambda(2000)$	$?^?$	$\star$	≈ 2000	73-240
	$2158 + i13$	2158	23					
$1, -1$	—	1830	42	$\Sigma(1750)$	$1/2^-$	$\star\star\star$	1730-1800	60-160
	—	1987	240	$\Sigma(1940)$	$3/2^-$	$\star\star\star$	1900-1950	150-300
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$1/2, -2$	$2039 + i67$	2039	64	$\Xi(1950)$	$?^?$	$\star\star\star$	1950 ± 15	60 ± 20
	$2083 + i31$	2077	29	$\Xi(2120)$	$?^?$	$\star$	≈ 2120	25

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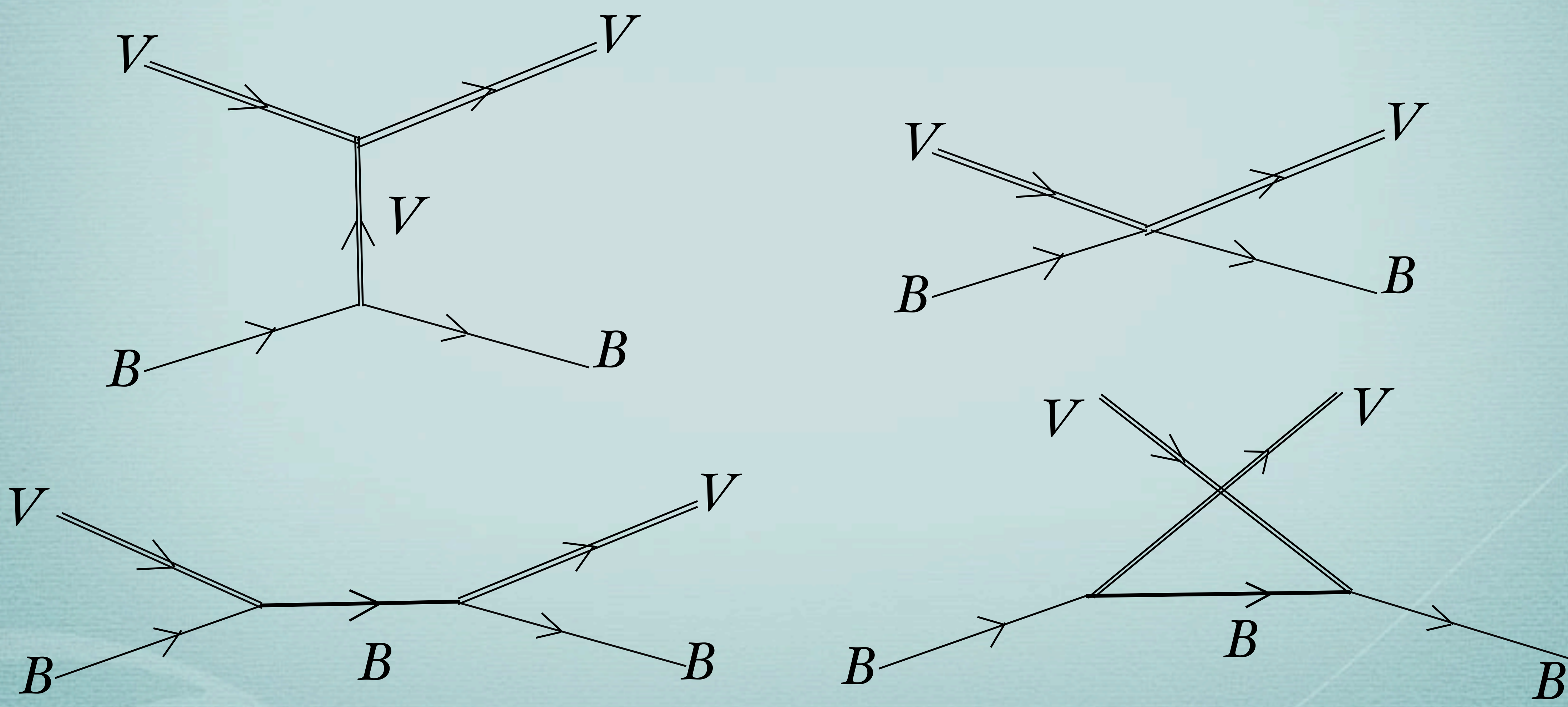
→ Spin degenerate

Vector Meson-Baryon interaction:

- Low energy theorems may not be applicable due to the heavy mass of the vector mesons.
- No apriori reason to neglect diagrams like S-channel, U-channel, contact interaction from hidden gauge Lagrangian, etc.
- It is important to check if diagrams other than W-T *(like)* interaction contribute significantly.

Diagrams, we include:

- t-channel exchange (Weinberg-Tomozawa *(like)* interaction).
- Contact interaction (Hidden gauge Lagrangian).
- s- and u-channel baryon exchange



and study strangeness zero systems to start with.

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$$\mathcal{L}_{VBB} = -g\left\{\langle \bar{B}\gamma_\mu \left[V^\mu, B\right]\rangle + \langle \bar{B}\gamma_\mu B\rangle\langle V^\mu\rangle + \frac{1}{4M}\left(F\langle \bar{B}\sigma_{\mu\nu}\left[V^{\mu\nu}, B\right]\rangle + D\langle \bar{B}\sigma_{\mu\nu}\left\{V^{\mu\nu}, B\right\}\rangle\right)\right\}$$

D = 2.4

F = 0.82

$$V^{\mu\nu} = \partial^\mu V^\nu - \partial^\nu V^\mu + ig[V^\mu, V^\nu]$$

$$V = \begin{pmatrix} \frac{\rho^0}{2} + \frac{\omega}{2} & \frac{\rho^+}{\sqrt{2}} & \frac{K^{*+}}{\sqrt{2}} \\ \frac{\rho^-}{\sqrt{2}} & -\frac{\rho^0}{2} + \frac{\omega}{2} & \frac{K^{*0}}{\sqrt{2}} \\ \frac{K^{*-}}{\sqrt{2}} & \frac{\bar{K}^{*0}}{\sqrt{2}} & \frac{\phi}{\sqrt{2}} \end{pmatrix} \qquad B = \begin{pmatrix} \frac{\Sigma^0}{\sqrt{2}} + \frac{\Lambda}{\sqrt{6}} & \Sigma^+ & p \\ \Sigma^- & -\frac{\Sigma^0}{\sqrt{2}} + \frac{\Lambda}{\sqrt{6}} & n \\ \Xi^- & \Xi^0 & \frac{-2\Lambda}{\sqrt{6}} \end{pmatrix}$$

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⟶ D + F = 3.22 $\approx \kappa_\rho$

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$\longrightarrow$ D + F = 3.22 $\approx \kappa_\rho$ $\quad g = \dfrac{m_v}{\sqrt{2} f_\pi}$

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Vector meson-Baryon t-channel (vector exchange) interaction:

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$$\boxed{V_t = -C^t_{ij} \frac{1}{4f_\pi^2} (k_1^0 + k_2^0) \vec{\epsilon_1} . \vec{\epsilon_2}}$$

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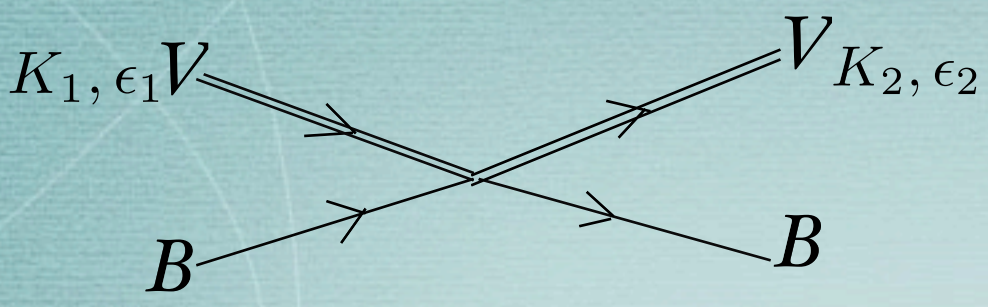
Vector-Baryon contact interaction:



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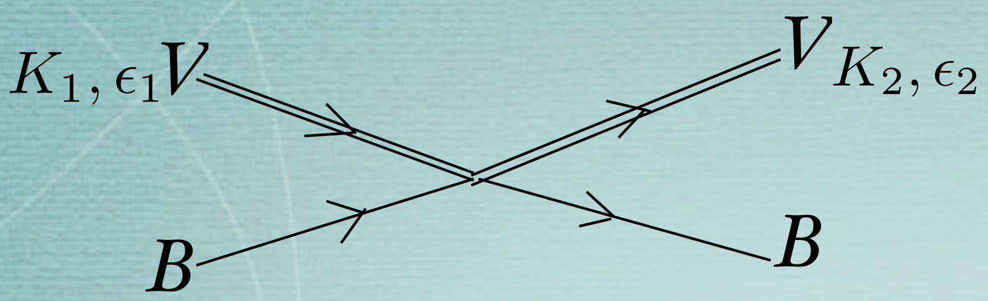

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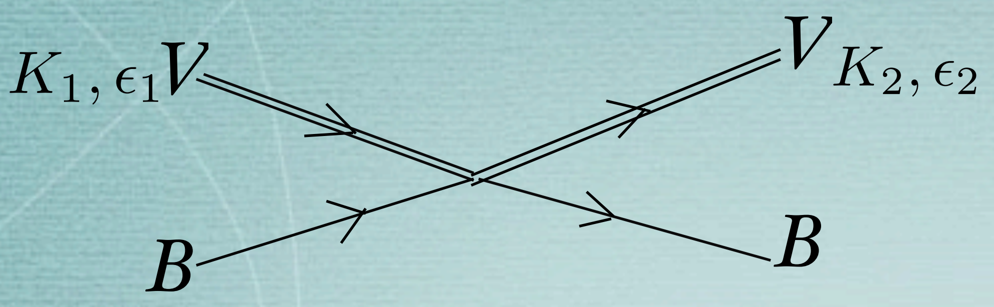

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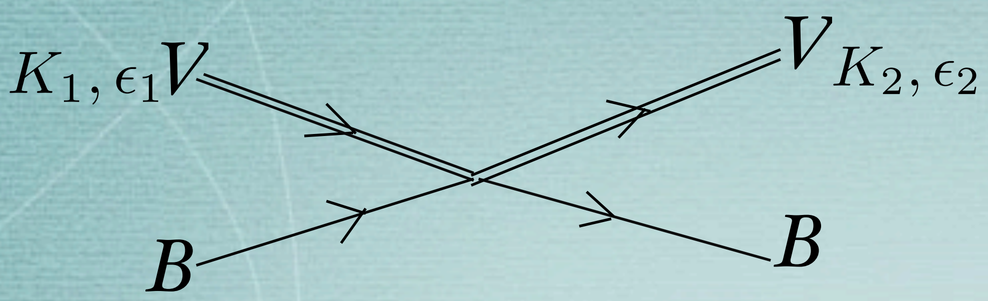

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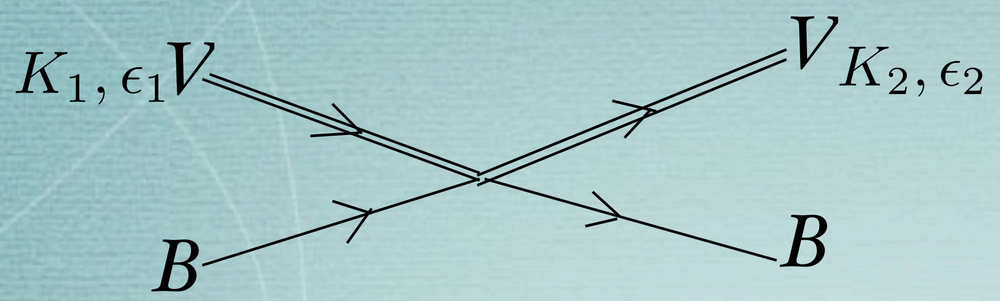

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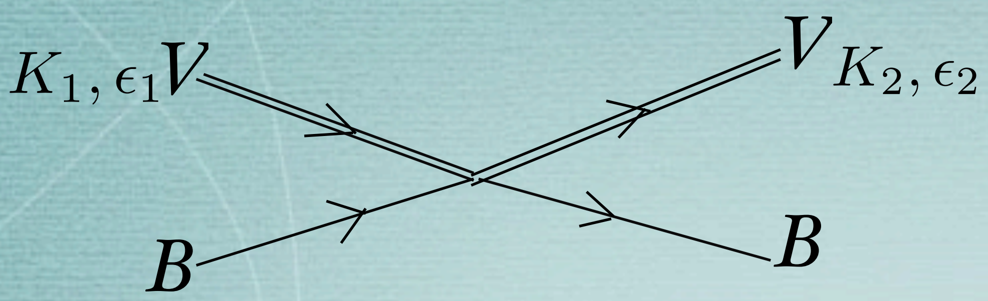

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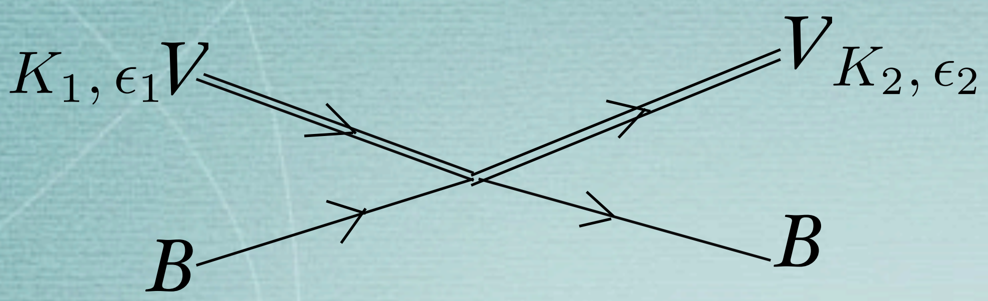

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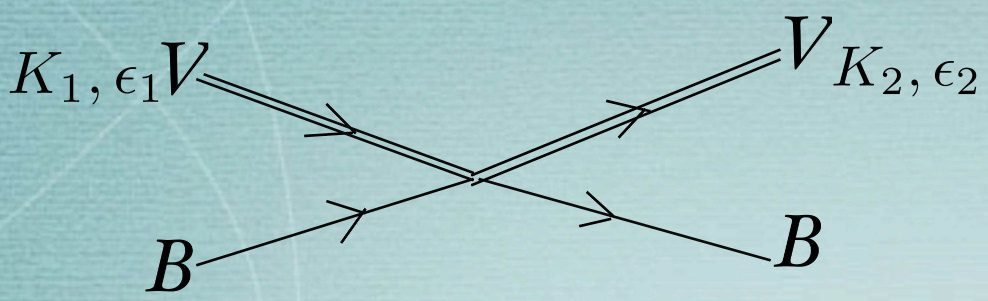

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Spin dependent

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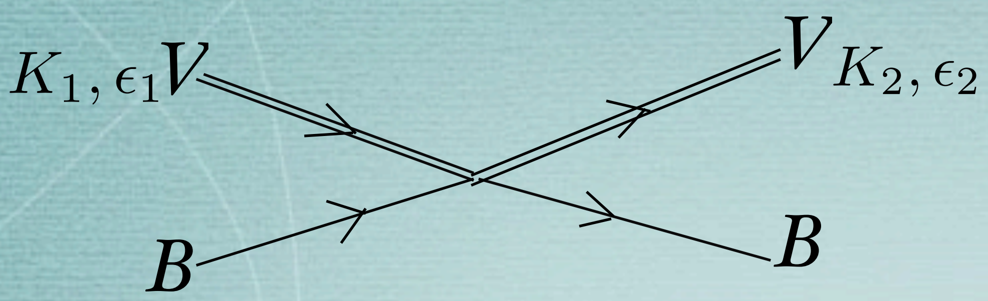

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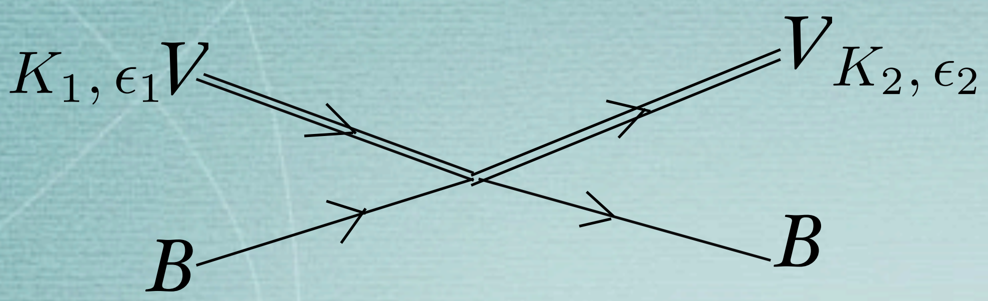

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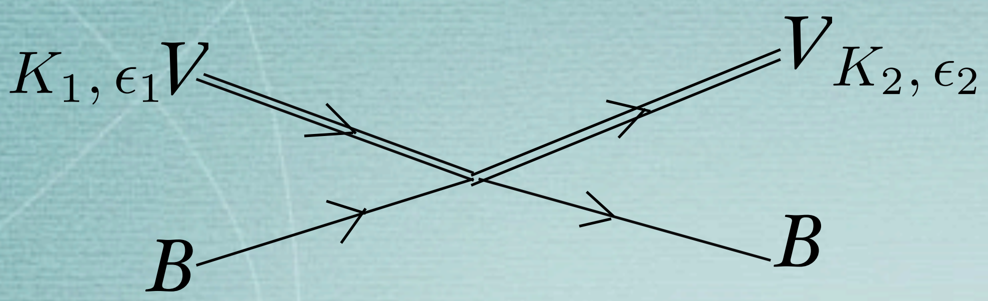


$$V^{\mu\nu} = \partial^\mu V^\nu - \partial^\nu V^\mu + ig[V^\mu, V^\nu] \qquad g = \frac{m_v}{\sqrt{2} f_\pi}$$

$$\mathcal{L}_{VVBB} = -\frac{g}{4M} \left\{ F \langle \bar{B} \sigma_{\mu\nu} \left[2ig \left[V^\mu, V^\nu \right], B \right] \rangle + D \langle \bar{B} \sigma_{\mu\nu} \left\{ \left[2ig \left[V^\mu, V^\nu \right], B \right\} \rangle \right) \right\}$$

$$V_{contact} = -i C_{ij}^{contact} \frac{g^2}{2M_B} \vec{\sigma} \cdot \underline{\vec{\epsilon_2} \times \vec{\epsilon_1}}$$

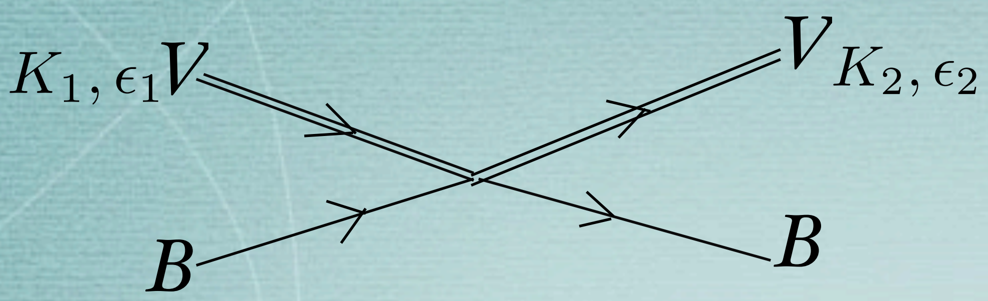
$$\vec{s} \cdot \; i\vec{S}$$

Spin dependent

$$V_{contact}^{1/2} = C_{ij}^{contact} \frac{g^2}{M_B}$$

$$V_{contact}^{3/2} = -C_{ij}^{contact} \frac{g^2}{2M_B}$$

Vector-Baryon contact interaction:



$$V^{\mu\nu} = \partial^\mu V^\nu - \partial^\nu V^\mu + ig[V^\mu, V^\nu] \qquad g = \frac{m_v}{\sqrt{2} f_\pi}$$

$$\mathcal{L}_{VVBB} = -\frac{g}{4M} \left\{ F \langle \bar{B} \sigma_{\mu\nu} \left[2ig \left[V^\mu, V^\nu \right], B \right] \rangle + D \langle \bar{B} \sigma_{\mu\nu} \left\{ \left[2ig \left[V^\mu, V^\nu \right], B \right\} \rangle \right) \right\}$$

$$\boxed{V_{contact} = -i C_{ij}^{contact} \frac{g^2}{2M_B} \vec{\sigma} \cdot \underline{\vec{\epsilon_2} \times \vec{\epsilon_1}}}$$

$$\vec{s} \cdot \; i\vec{S}$$

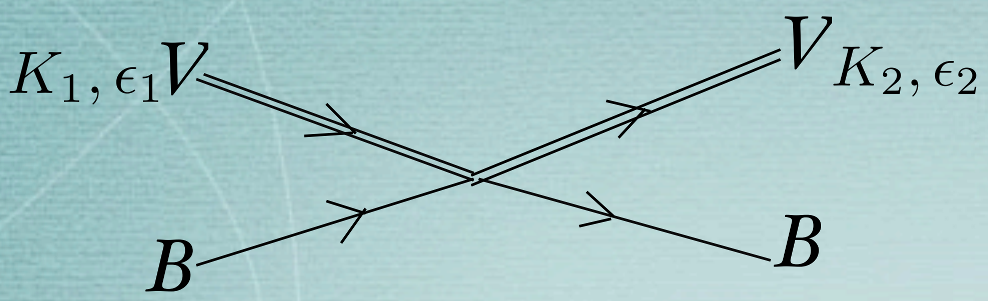
Spin dependent

$$V_{contact}^{1/2} = C_{ij}^{contact} \frac{g^2}{M_B}$$

$$= C_{ij}^{contact} \frac{m^2}{2 f_\pi} \frac{1}{M_B}$$

$$V_{contact}^{3/2} = -C_{ij}^{contact} \frac{g^2}{2M_B}$$

Vector-Baryon contact interaction:



$$V^{\mu\nu} = \partial^\mu V^\nu - \partial^\nu V^\mu + ig[V^\mu, V^\nu] \qquad g = \frac{m_v}{\sqrt{2} f_\pi}$$

$$\mathcal{L}_{VVBB} = -\frac{g}{4M}\left\{F\langle \bar{B}\sigma_{\mu\nu}\left[2ig\left[V^\mu, V^\nu\right], B\right]\rangle + D\langle \bar{B}\sigma_{\mu\nu}\left\{\left[2ig\left[V^\mu, V^\nu\right], B\right\}\rangle\right)\right\}$$

$$V_{contact} = -iC_{ij}^{contact}\frac{g^2}{2M_B}\vec{\sigma}\cdot\underline{\vec{\epsilon_2}\times\vec{\epsilon_1}}$$

$$\vec{s}\cdot \quad i\vec{S}$$

Spin dependent

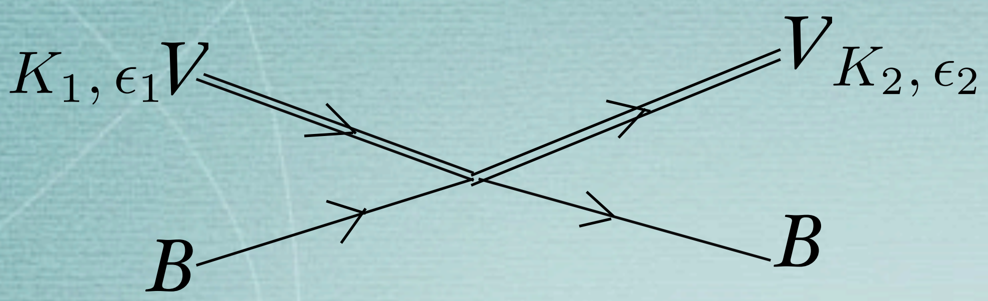
$$V_{contact}^{1/2} = C_{ij}^{contact}\frac{g^2}{M_B}$$

$$= C_{ij}^{contact}\frac{m^2}{2f_\pi}\frac{1}{M_B}$$

$$\sim C_{ij}^{contact}\frac{m}{2f_\pi^2}$$

$$V_{contact}^{3/2} = -C_{ij}^{contact}\frac{g^2}{2M_B}$$

Vector-Baryon contact interaction:



$$V^{\mu\nu} = \partial^\mu V^\nu - \partial^\nu V^\mu + ig[V^\mu, V^\nu] \qquad g = \frac{m_v}{\sqrt{2} f_\pi}$$

$$\mathcal{L}_{VVBB} = -\frac{g}{4M}\left\{F\langle \bar{B}\sigma_{\mu\nu}\left[2ig\left[V^\mu, V^\nu\right], B\right]\rangle + D\langle \bar{B}\sigma_{\mu\nu}\left\{\left[2ig\left[V^\mu, V^\nu\right], B\right\}\rangle\rangle\right\}$$

$$V_{contact} = -iC_{ij}^{contact}\frac{g^2}{2M_B}\vec{\sigma}\cdot\underline{\vec{\epsilon_2}\times\vec{\epsilon_1}}$$

$$\vec{s}\cdot \quad i\vec{S}$$

Spin dependent

$$V_{contact}^{1/2} = C_{ij}^{contact}\frac{g^2}{M_B}$$

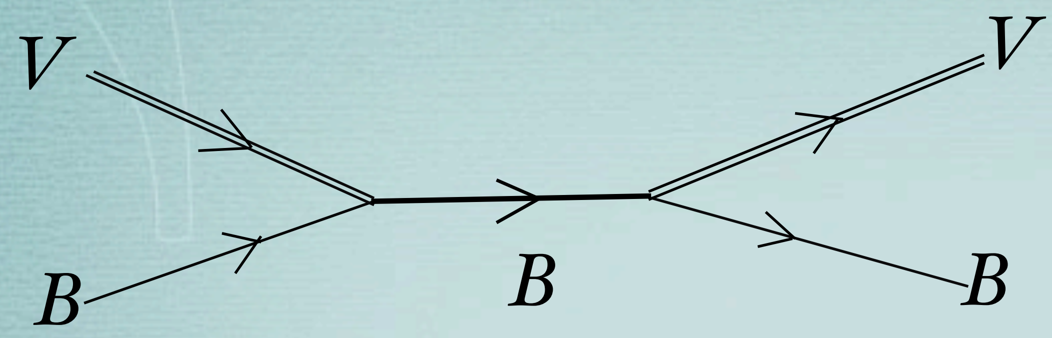
$$= C_{ij}^{contact}\frac{m^2}{2f_\pi}\frac{1}{M_B}$$

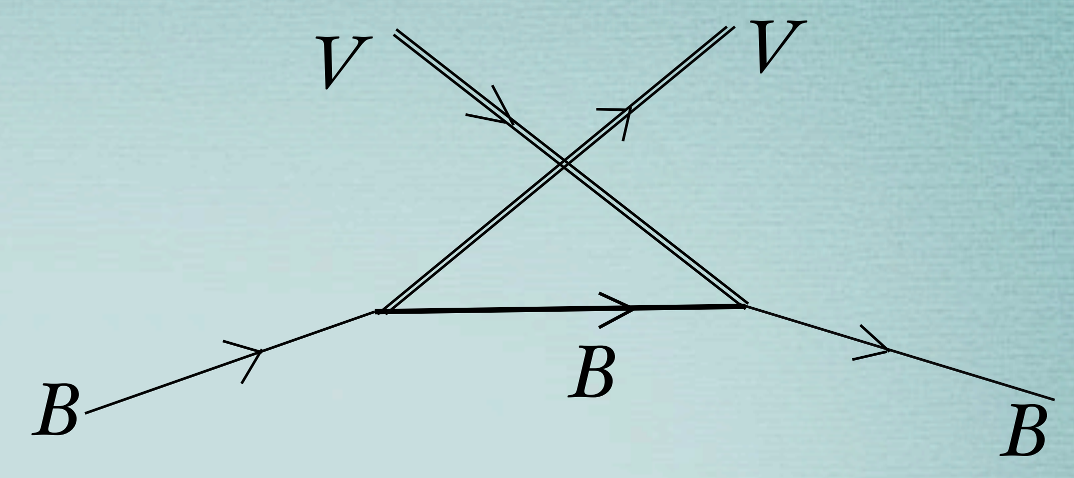
$$\sim C_{ij}^{contact}\frac{m}{2f_\pi^2}$$

$$V_{contact}^{3/2} = -C_{ij}^{contact}\frac{g^2}{2M_B}$$

$$\sim -C_{ij}^{contact}\frac{m}{4f\pi^2}$$

S- and U-channel diagrams:





$$\mathcal{L}_{VBB} = -g \left\{ \langle \bar{B}\gamma_\mu \left[V^\mu, B\right] \rangle + \langle \bar{B}\gamma_\mu B \rangle \langle V^\mu \rangle + \frac{1}{4M} \left(F \langle \bar{B}\sigma_{\mu\nu} \left[V^{\mu\nu}, B\right] \rangle + D \langle \bar{B}\sigma_{\mu\nu} \left\{V^{\mu\nu}, B\right\} \rangle \right) \right\}$$

$$V_S = C^s_{ij}\, g^2 \left(\frac{1}{m_v + 2M_B} \right) \underline{\vec{\epsilon_2} \cdot \vec{\sigma} \vec{\epsilon_1} \cdot \vec{\sigma}}$$

$$\vec{\epsilon_2} \cdot \vec{\epsilon_1} + i\, \vec{\sigma} \cdot \vec{\epsilon_2} \times \vec{\epsilon_1}$$

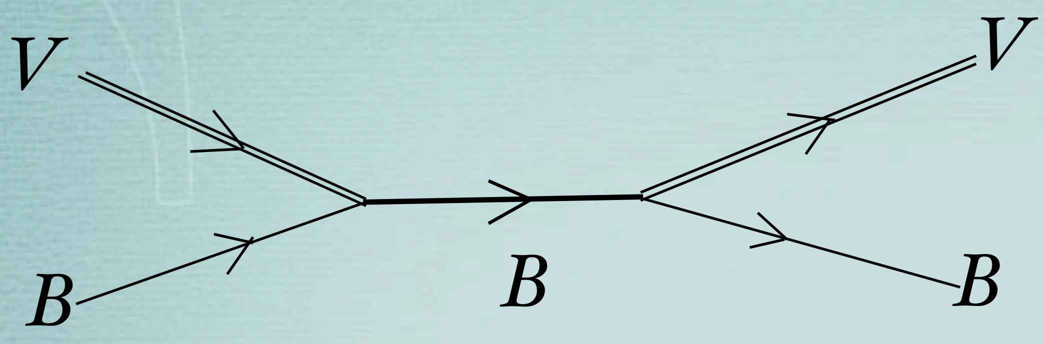
$$V_U = -C^u_{ij}\, g^2 \left(\frac{1}{m_v - 2M_B} \right) \underline{\vec{\epsilon_1} \cdot \vec{\sigma} \vec{\epsilon_2} \cdot \vec{\sigma}}$$

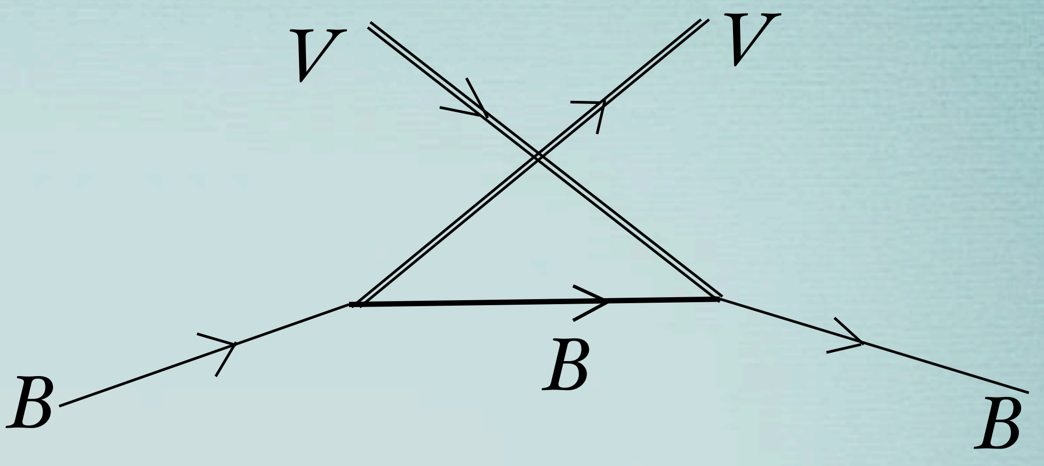
$$\vec{\epsilon_1} \cdot \vec{\epsilon_2} + i\, \vec{\sigma} \cdot \vec{\epsilon_1} \times \vec{\epsilon_2}$$

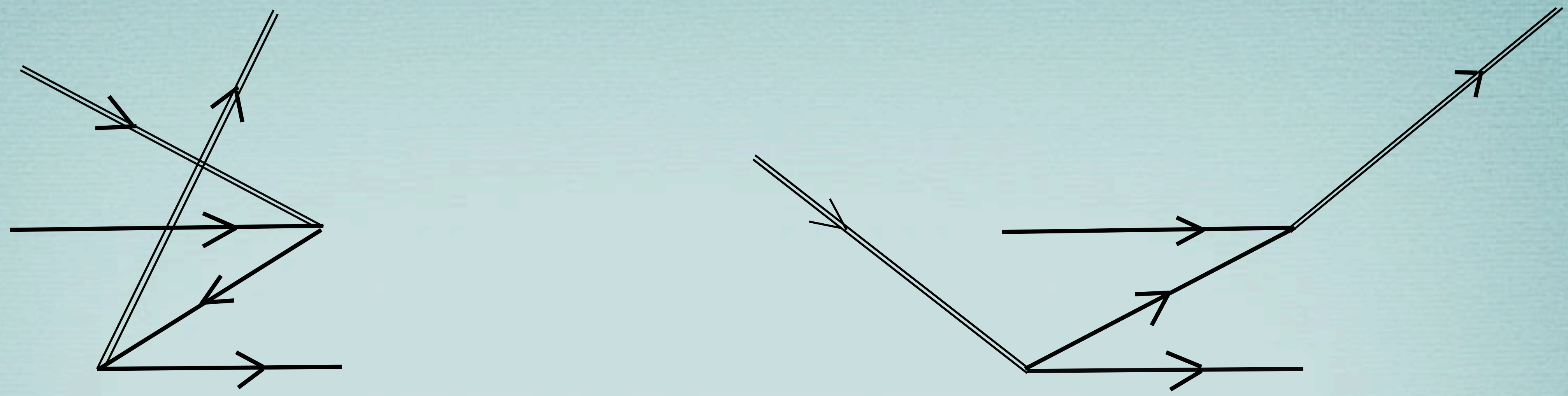
$$V_S^{1/2} = 3C^s_{ij} \left(\frac{g^2}{m_v + 2M_B} \right)$$

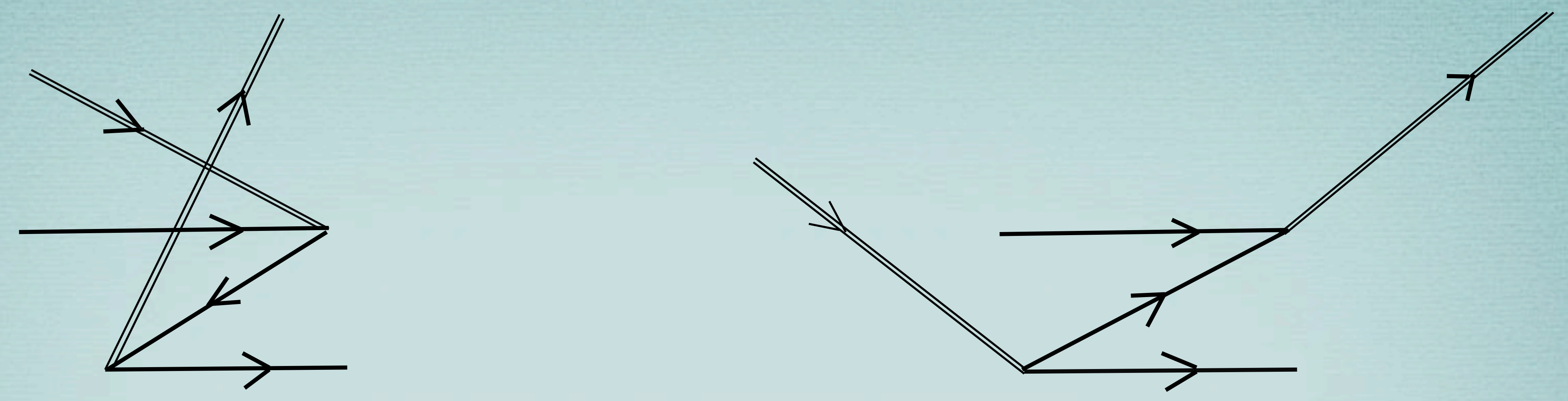
$$V_U^{1/2} = -C^u_{ij} \left(\frac{g^2}{2M_B - m_v} \right)$$

$$V_U^{3/2} = 2C^u_{ij} \left(\frac{g^2}{2M_B - m_v} \right)$$


V
V
B
B
B


V
V
B
B
B





$$F(x)(\lambda, x) = \frac{\lambda^4}{\lambda^4 + \left(x^2 - M_x^2\right)^2}$$

$\lambda =$ 650 - 850 MeV

$x =$ s, u

Solve Bethe-Salpeter equations in coupled channel formalism:

T = V + VGT

$$V = V_t + V_{contact} + V_u + V_s$$

$$G = i2M \int \frac{d^4q}{2\pi^4} \frac{1}{(P-q)^2 - M^2 + i\epsilon} \frac{1}{q^2 - m^2 + i\epsilon}$$
$$= \frac{2M}{16\pi^2} \Bigg\{ a(\mu) + ln\frac{M^2}{\mu^2} + \frac{m^2 - M^2 + s}{2s} ln\frac{m^2}{M^2}$$
$$+ \frac{\bar{q}}{\sqrt{s}} \Big[ln\left(s - \left(M^2 - m^2\right) + 2\bar{q}\sqrt{s}\right) - ln\left(-s + \left(M^2 - m^2\right) + 2\bar{q}\sqrt{s}\right)$$
$$- ln\left(s - \left(M^2 - m^2\right) + 2\bar{q}\sqrt{s}\right) \Big] \Bigg\}$$

But rho and K* mesons are quite wide!!

T = V + VGT

$$\tilde{G}(s) = \frac{1}{N} \int_{(m-2\Gamma_i)^2}^{(m+2\Gamma_i)^2} \mathrm{d}\tilde{m}^2 \left(-\frac{1}{\pi}\right) \times \mathrm{Im}\, \frac{1}{\tilde{m}^2 - m^2 + \mathrm{i}m\Gamma(\tilde{m})} G(s, \tilde{m}^2, \tilde{M}_B^2),$$

with

$$N = \int_{(m-2\Gamma_i)^2}^{(m+2\Gamma_i)^2} \mathrm{d}\tilde{m}^2 \left(-\frac{1}{\pi}\right) \mathrm{Im}\, \frac{1}{\tilde{m}^2 - m^2 + \mathrm{i}m\Gamma(\tilde{m})}$$

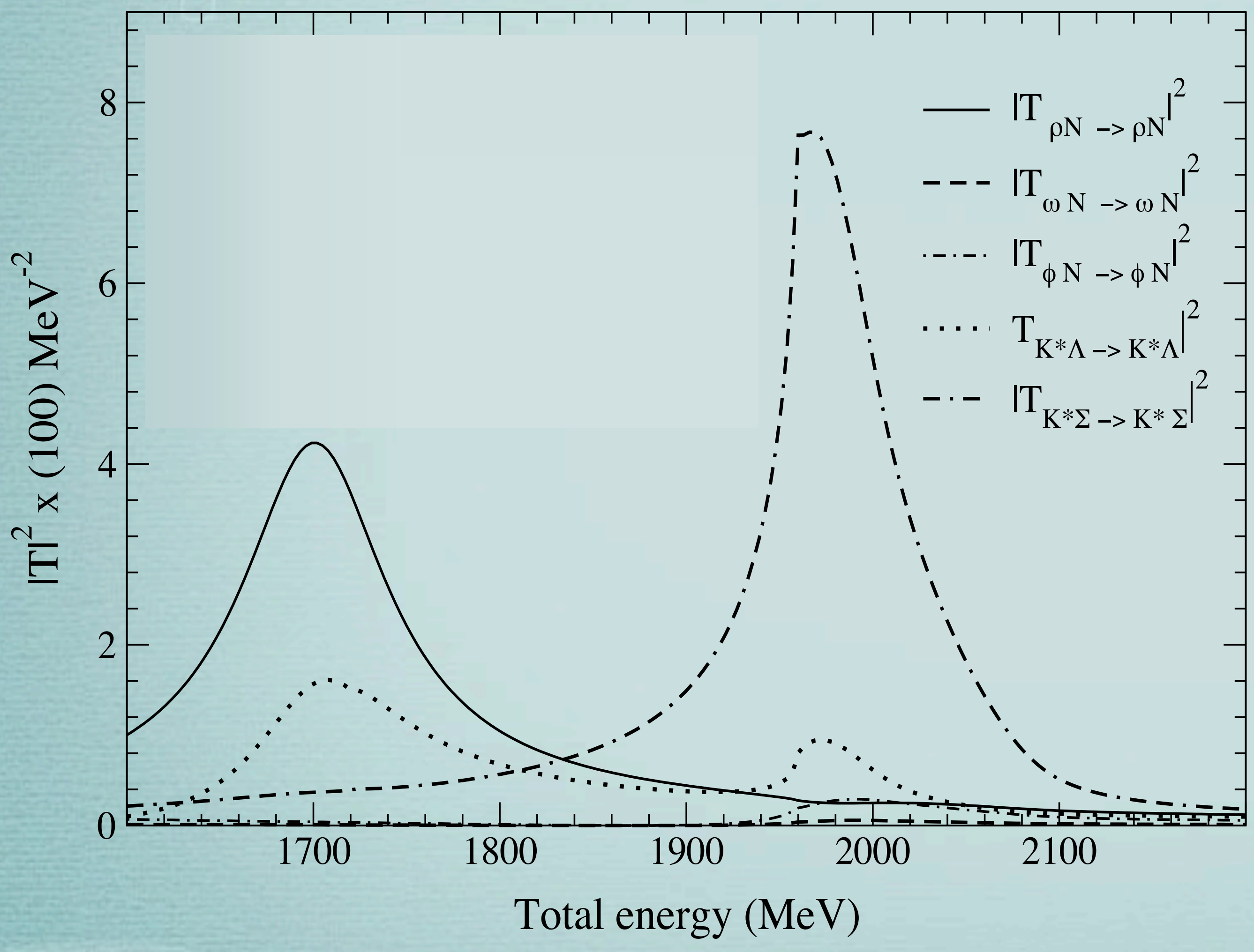
where, for example, for rho meson --> 2 pions

$$\Gamma(\tilde{m}) = \Gamma_\rho \frac{m_\rho^2}{\tilde{m}^2} \left(\frac{\tilde{m}^2 - 4m_\pi^2}{m_\rho^2 - 4m_\pi^2}\right)^{3/2} \theta(\tilde{m} - 2m_\pi).$$

Ref: E. Oset and A. Ramos
(EPJA 44, 445 (2010))

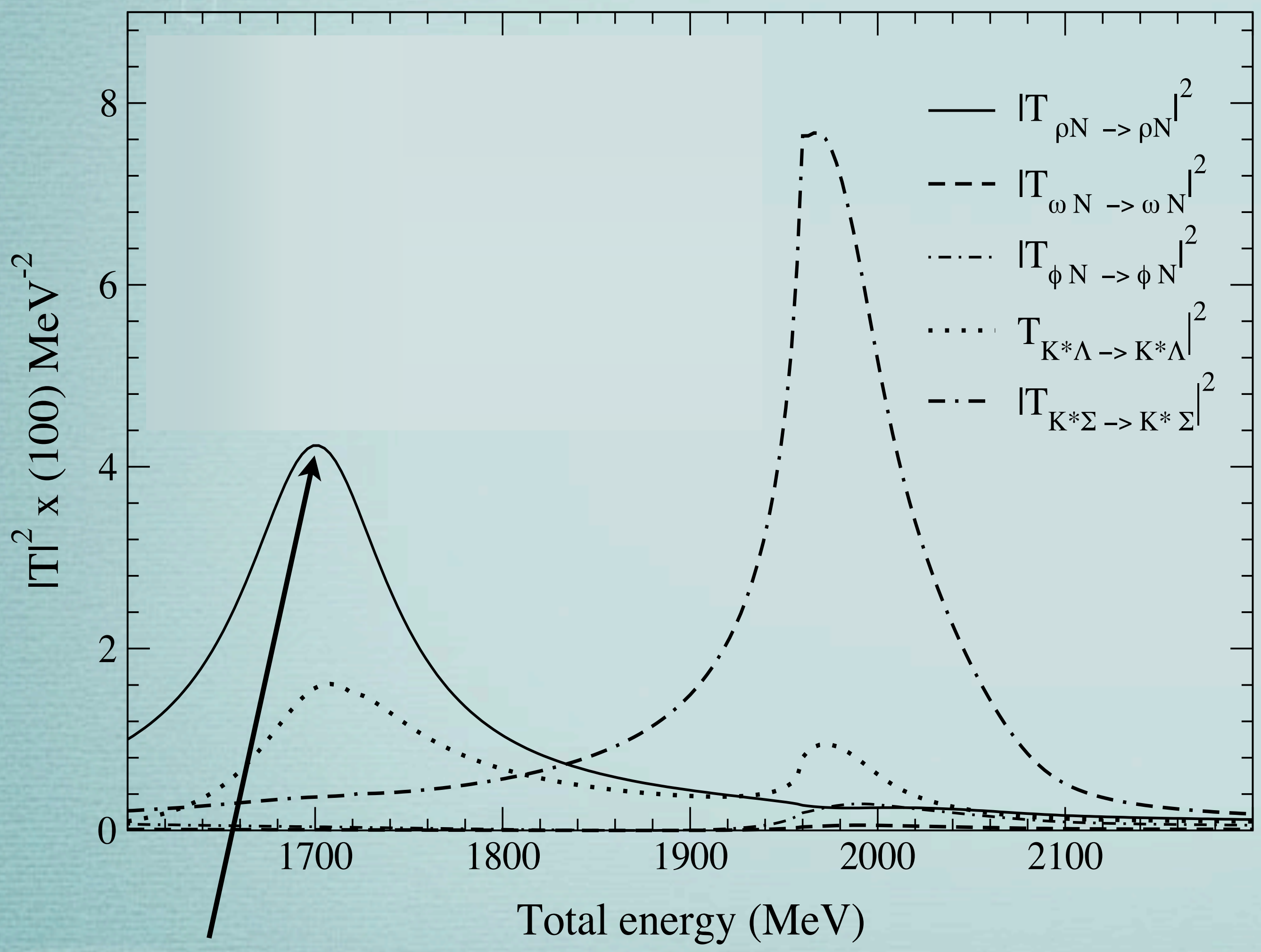
Results:

- t-channel: Isospin=1/2, spin=1/2,3/2



Results:

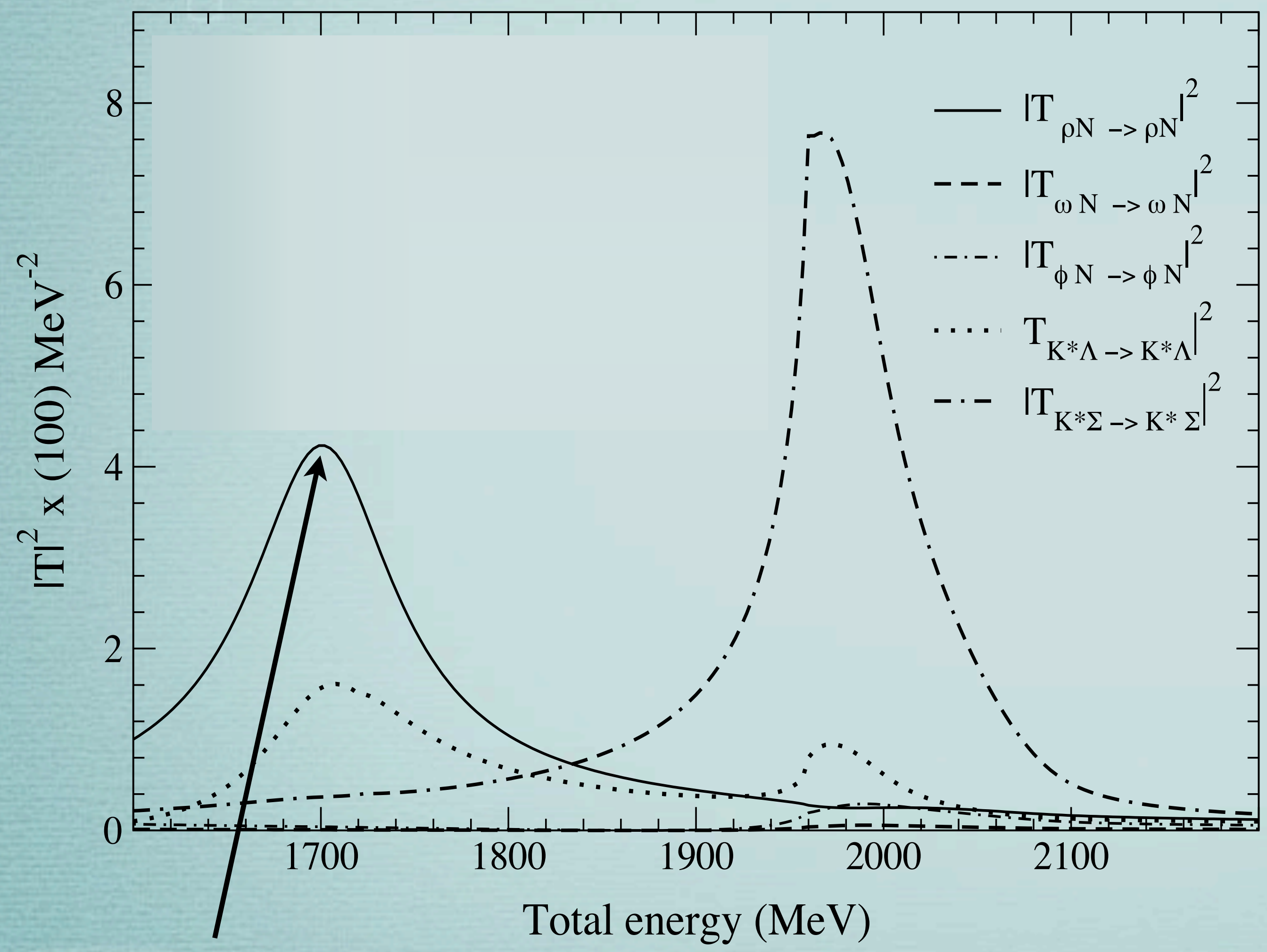
- t-channel: Isospin=1/2, spin=1/2,3/2



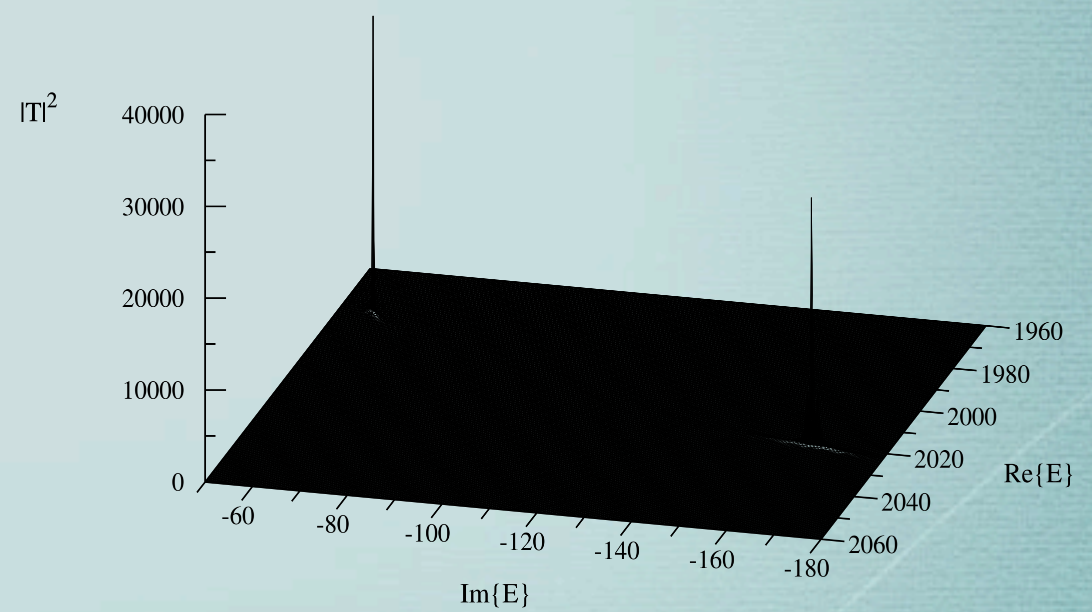
1702 + i0 MeV

Results:

- t-channel: Isospin=1/2, spin=1/2,3/2

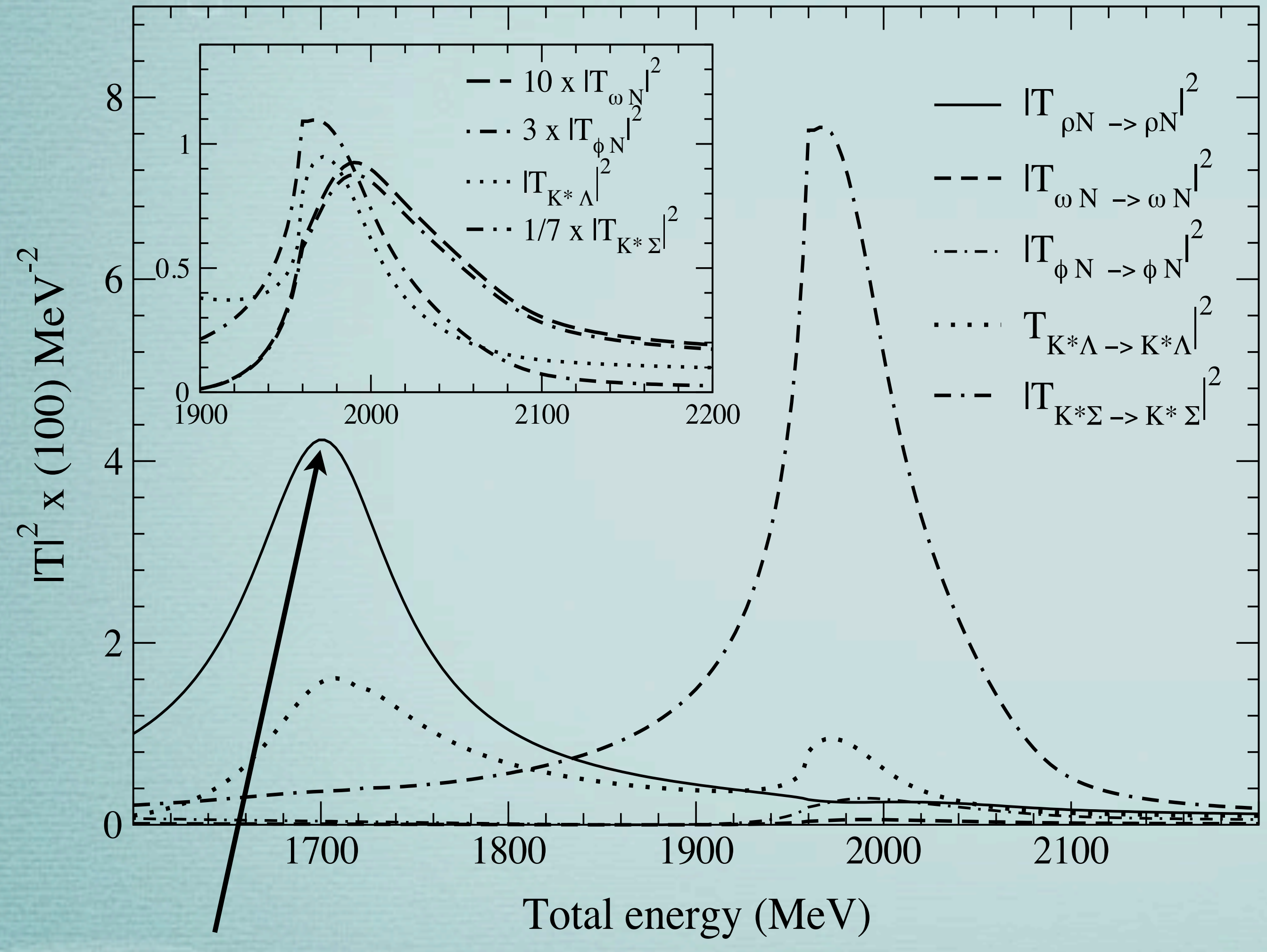


1702 + i0 MeV

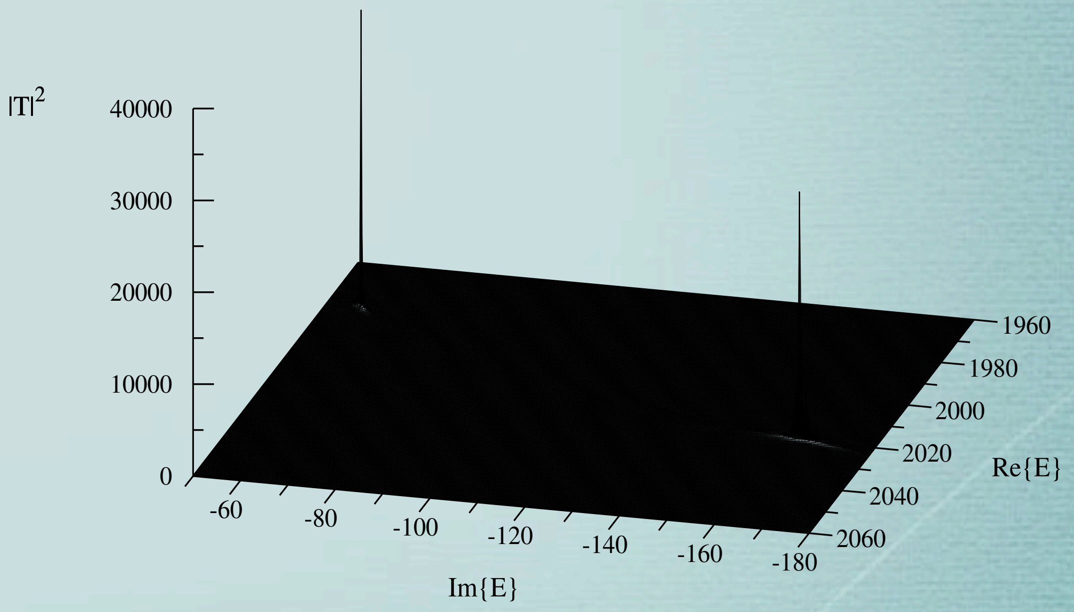


Results:

- t-channel: Isospin=1/2, spin=1/2,3/2

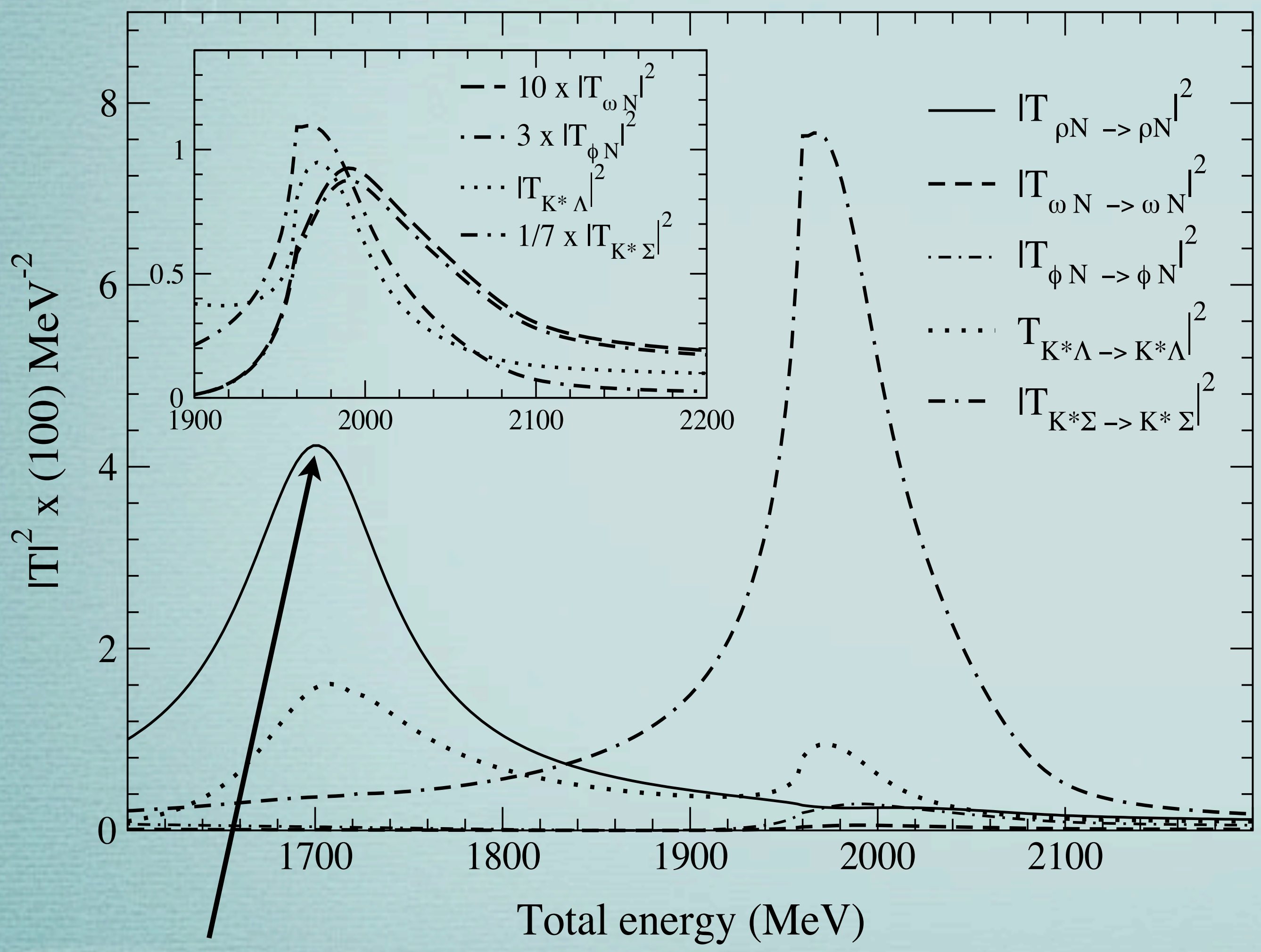


1702 + i0 MeV

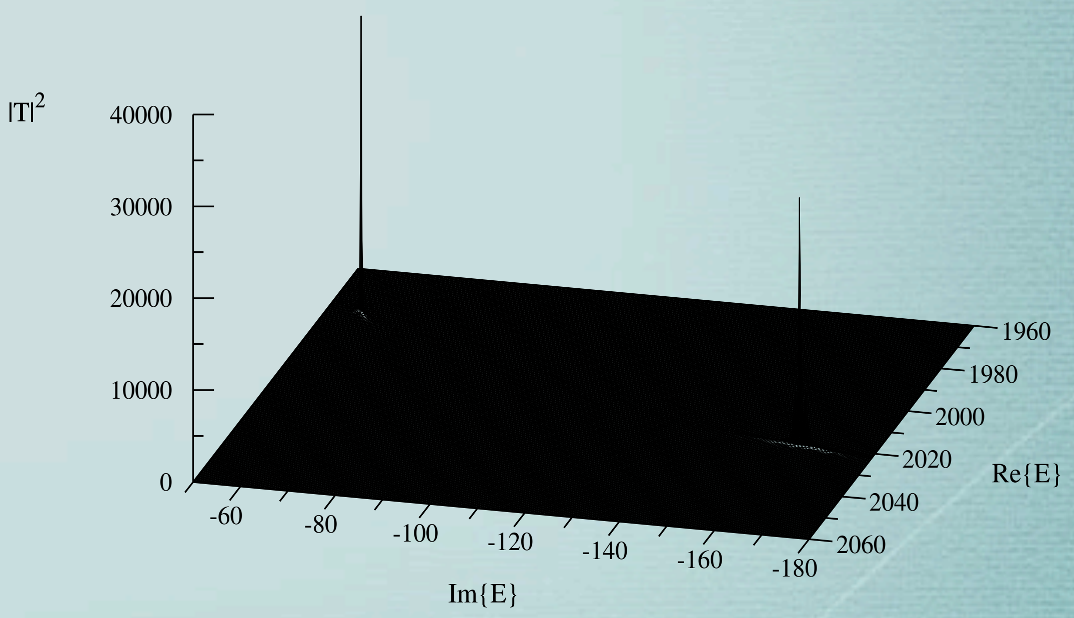


Results:

- t-channel: Isospin=1/2, spin=1/2,3/2



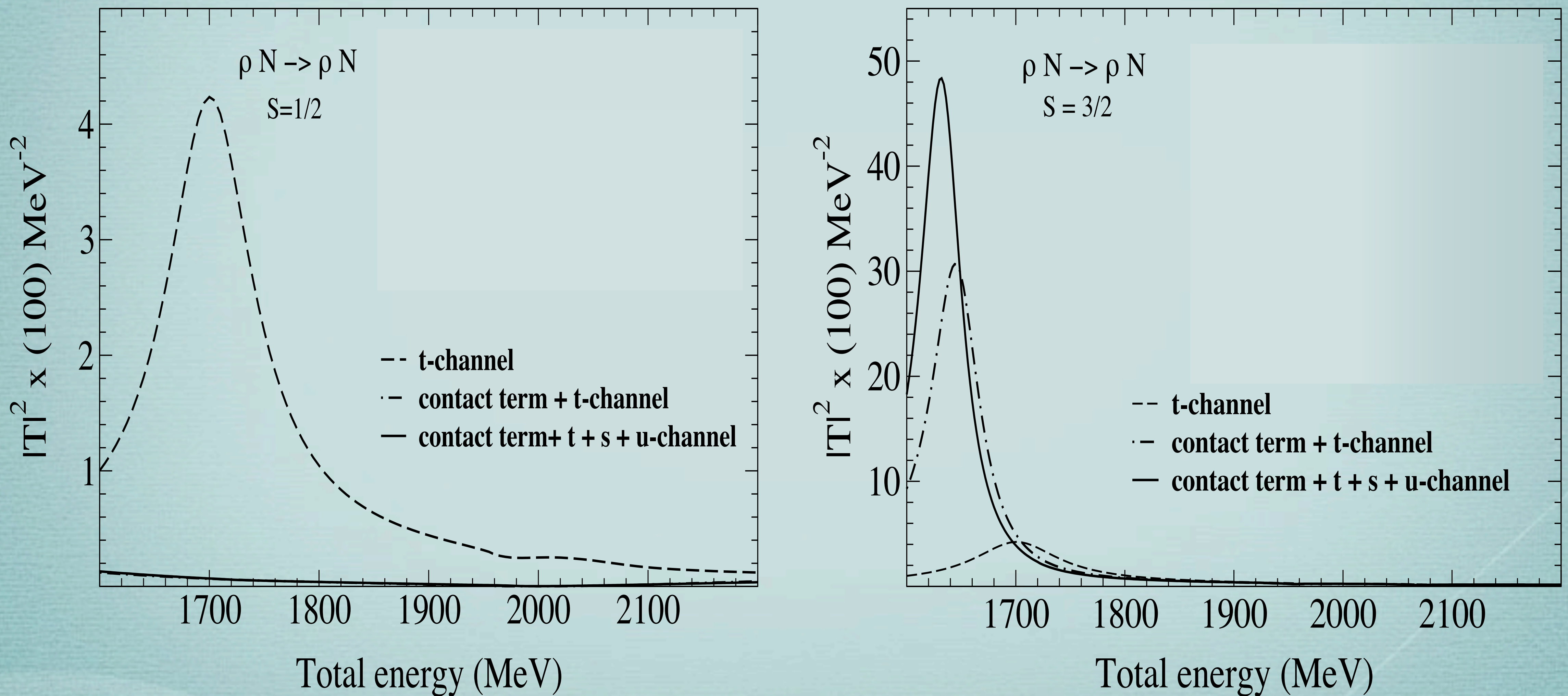
1702 + i0 MeV



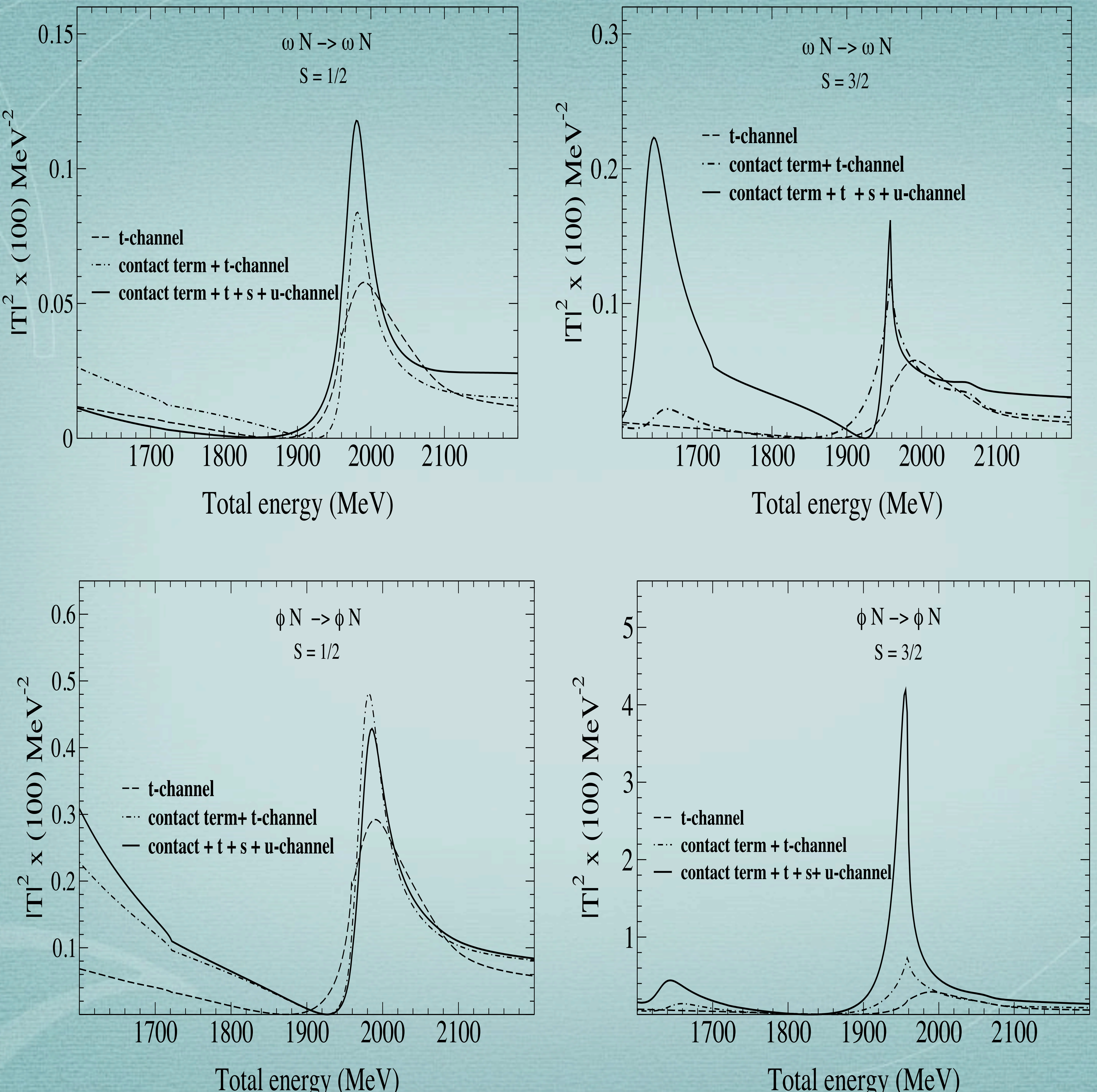
No states found with isospin=3/2.

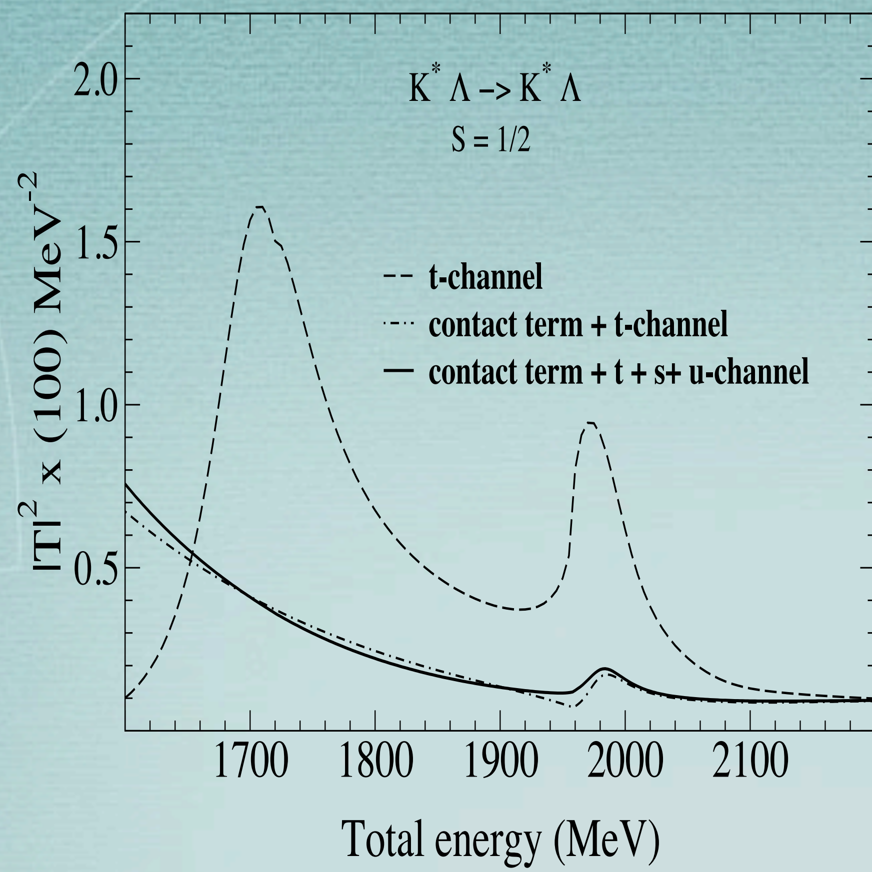
- Adding more diagrams:

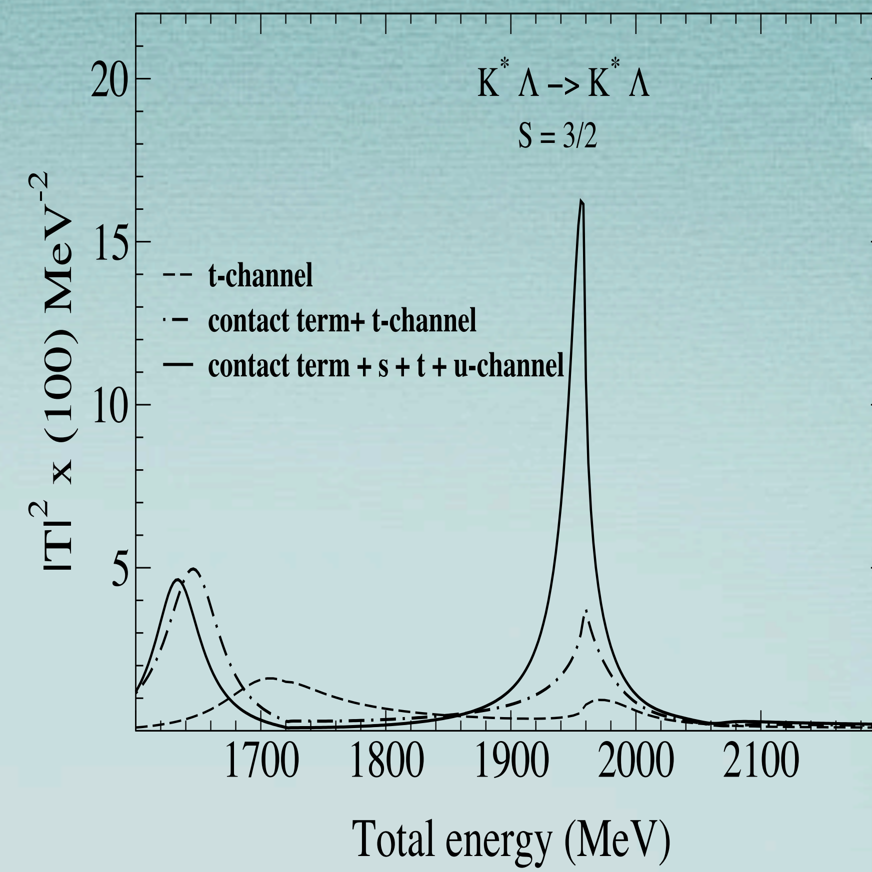
Isospin=1/2

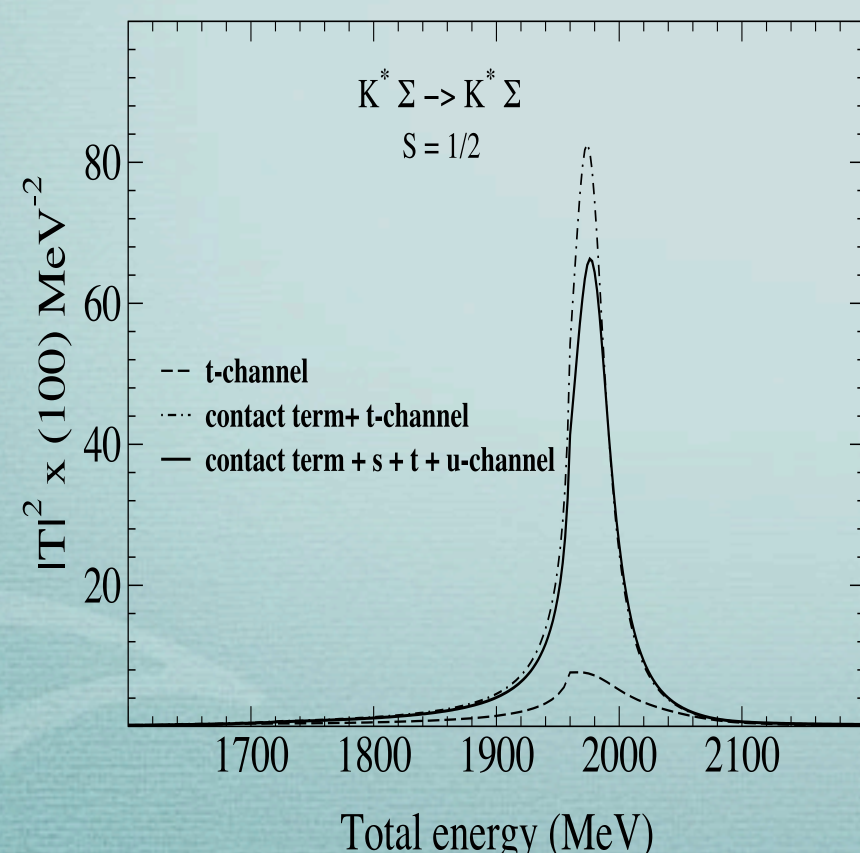


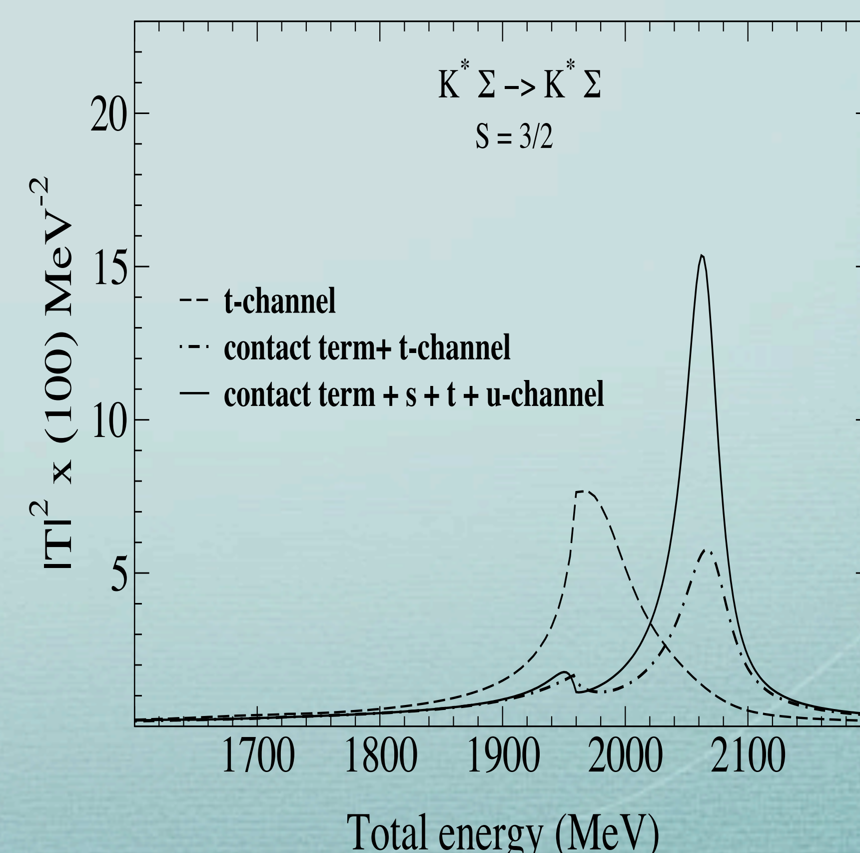
$\lambda = 650$ MeV


ω N -> ω N
S = 1/2
t-channel
contact term + t-channel
contact term + t + s + u-channel
|T|^2 x (100) MeV^{-2}
Total energy (MeV)
ω N -> ω N
S = 3/2
t-channel
contact term+ t-channel
contact term + t + s + u-channel
|T|^2 x (100) MeV^{-2}
Total energy (MeV)
ϕ N -> ϕ N
S = 1/2
t-channel
contact term+ t-channel
contact + t + s + u-channel
|T|^2 x (100) MeV^{-2}
Total energy (MeV)
ϕ N -> ϕ N
S = 3/2
t-channel
contact term + t-channel
contact term + t + s+ u-channel
|T|^2 x (100) MeV^{-2}
Total energy (MeV)


K* Λ -> K* Λ
S = 1/2
t-channel
contact term + t-channel
contact term + t + s+ u-channel
|T|^2 x (100) MeV^-2
0.5
1.0
1.5
2.0
1700
1800
1900
2000
2100
Total energy (MeV)

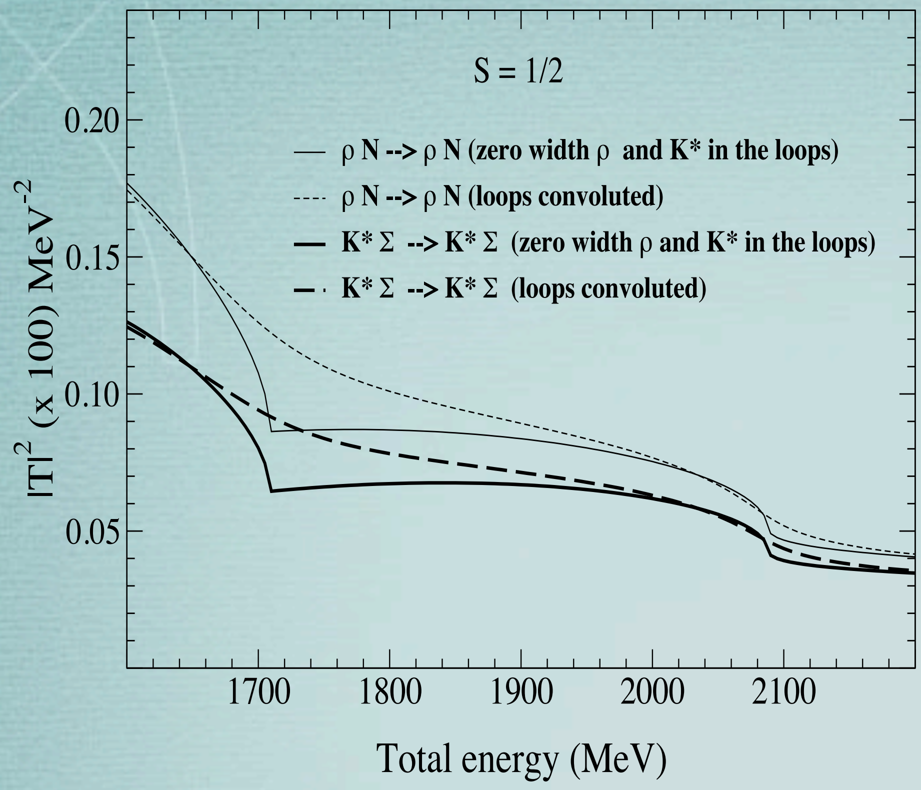

K* Λ -> K* Λ
S = 3/2
t-channel
contact term+ t-channel
contact term + s + t + u-channel
|T|^2 x (100) MeV^-2
5
10
15
20
1700
1800
1900
2000
2100
Total energy (MeV)


K* Σ -> K* Σ
S = 1/2
t-channel
contact term+ t-channel
contact term + s + t + u-channel
|T|^2 x (100) MeV^-2
20
40
60
80
1700
1800
1900
2000
2100
Total energy (MeV)

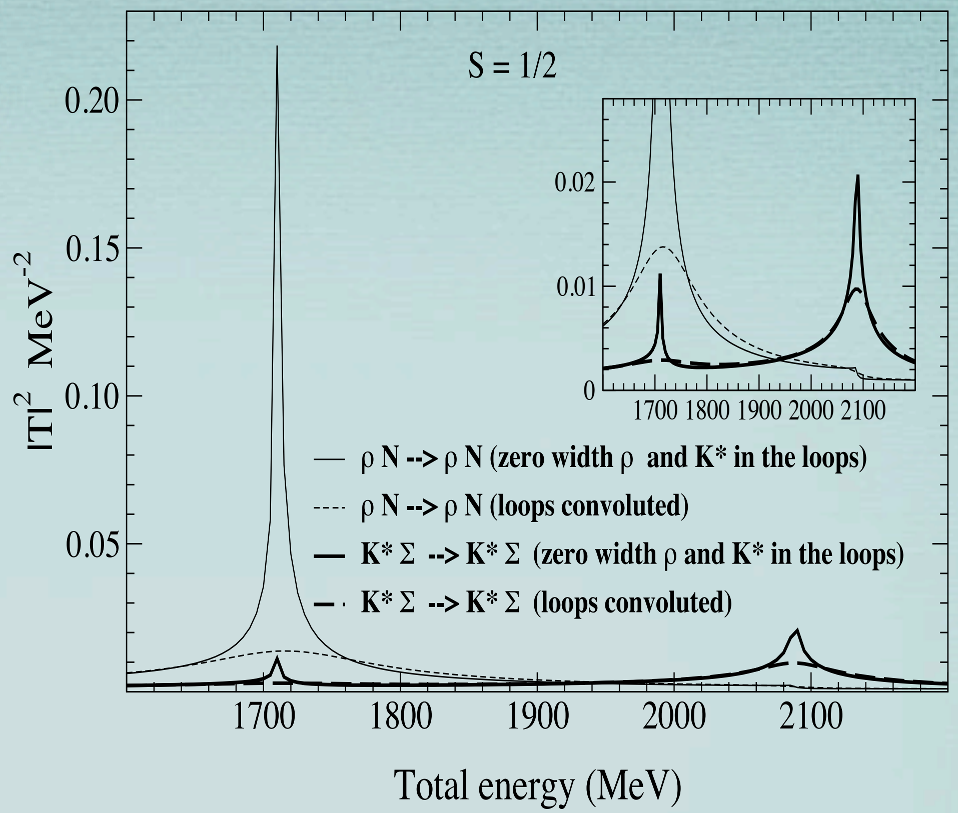

K* Σ -> K* Σ
S = 3/2
t-channel
contact term+ t-channel
contact term + s + t + u-channel
|T|^2 x (100) MeV^-2
5
10
15
20
1700
1800
1900
2000
2100
Total energy (MeV)

Isospin 3/2:

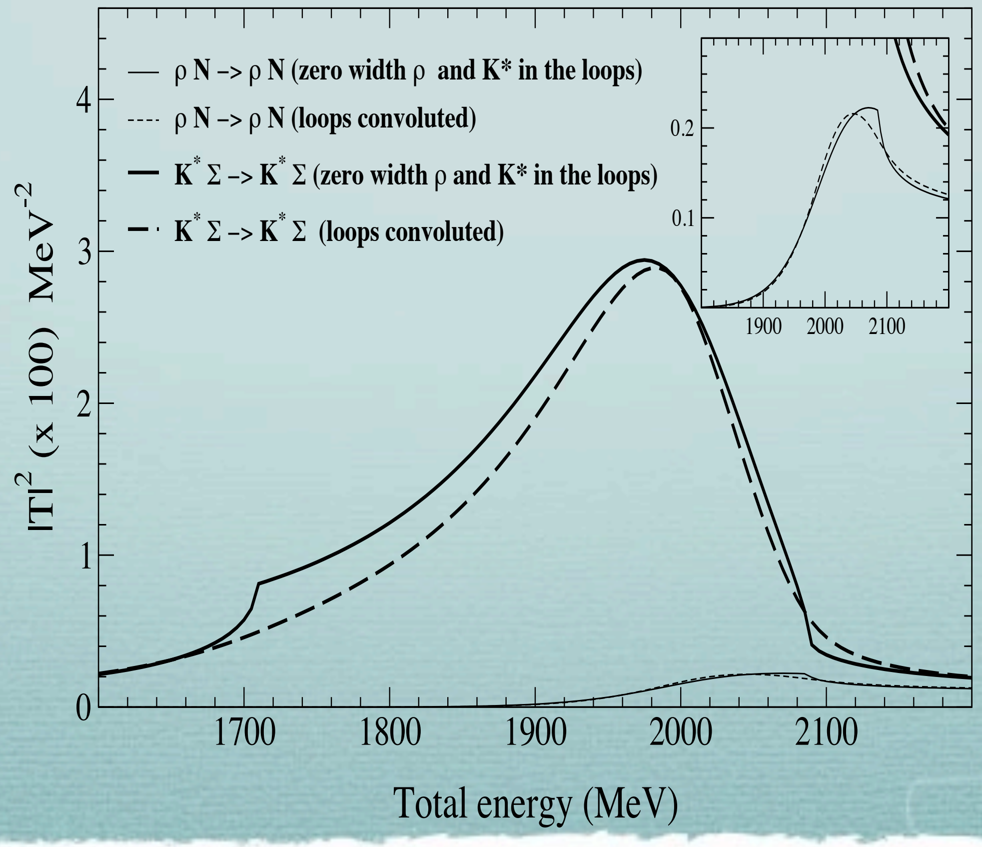
- t-channel



- Contact interaction



- t- + u-channel
+ contact inetarction



Summary:

- The tree-level contributions from the contact term obtained from hidden gauge Lagrangian and from the s- and u- channel exchange diagrams are not negligible.

- The degeneracy in the WT results gets lifted if the contribution from these different diagrams is added. This is something which should be expected when two particles with spin interact.

- States found and tentative correspondence to known resonances:

Isospin, Spin-parity	pole positions	States in PDG
$1/2, 1/2^-$	1977 - i27	N* (2090)
$1/2, 3/2^-$	1641 - i0	N* (1700)
$1/2, 3/2^-$	2071 - i7	N* (2080)
$3/2, 1/2^-$	2010 - i112	Δ(1900)

t-channel exchange

$$V_t \sim -C^t_{ij} \frac{m}{2f_\pi^2}$$

I=1/2

	ρN	ωN	ϕN	$K^*\Lambda$	$K^*\Sigma$
ρN	2	0	0	$\frac{3}{2}$	$-\frac{1}{2}$
ωN		0	0	$-\frac{3}{2}\frac{1}{\sqrt{3}}$	$-\frac{3}{2}\frac{1}{\sqrt{3}}$
ϕN			0	$-\frac{3}{2}\left(-\sqrt{\frac{2}{3}}\right)$	$-\frac{3}{2}\left(-\sqrt{\frac{2}{3}}\right)$
$K^*\Lambda$				0	0
$K^*\Sigma$					2

I=3/2

	ρN	$K^*\Sigma$
ρN	-1	-1
$K^*\Sigma$		-1

Extra slides

Contact interaction:

$$V^{1/2}_{contact} \sim C^{contact}_{ij} \frac{m}{2f_\pi^2}$$

$$V^{3/2}_{contact} \sim -C^{contact}_{ij} \frac{m}{4f_\pi^2}$$

$C^{contact}_{ij}$	ρN	ωN	ϕN	$K^*\Lambda$	$K^*\Sigma$
ρN	(D+F)	0	0	$\frac{(D+3F)}{4}$	$-\frac{(F-D)}{4}$
ωN		0	0	$\frac{-(D+3F)}{4\sqrt{3}}$	$-\frac{\sqrt{3}(F-D)}{4}$
ϕN			0	$\frac{(D+3F)}{(2\sqrt{6})}$	$-\sqrt{\frac{3}{2}}\frac{(D-F)}{2}$
$K^*\Lambda$				$\frac{D}{2}$	$-\frac{D}{2}$
$K^*\Sigma$					$\frac{(2F-D)}{2}$

$C^{contact}_{ij}$	ρN	$K^*\Sigma$
ρN	$-\frac{(D+F)}{2}$	$\frac{(D-F)}{2}$
$K^*\Sigma$		$-\frac{(D+F)}{2}$

D = 2.4 F = 0.82

u-channel:

$$V_U^{1/2} = -C_{ij}^u \left(\frac{g^2}{2M_B - m_v} \right)$$

$$V_U^{3/2} = 2C_{ij}^u \left(\frac{g^2}{2M_B - m_v} \right)$$

I=3/2

C_{ij}^u	ρN	$K^*\Sigma$
ρN	$\frac{[(D+F)m+2M]^2}{8M^2}$	$\frac{1}{8M^2}\left\{\frac{-Dm}{3}[(D+3F)m+6M] + [(F-D)m+2M][Fm+2M]\right\}$
$K^*\Sigma$		$\frac{((D+F)m+2M)^2}{8M^2}$

I=1/2

C_{ij}^u	ρN	ωN	ϕN	$K^*\Lambda$	$K^*\Sigma$
ρN	$-\frac{[(D+F)m+2M]^2}{16M^2}$	$\frac{\sqrt{3}}{16M^2} * [(D-3F)m-6M] * [(D+F)m+2M]$	0	$\frac{Dm*[(F-D)m+2M]}{8M^2}$	$\frac{(Fm+2M)[(F-D)m+2M]}{4M^2}$ $\frac{Dm*[(D+3F)m+6M]}{24M^2}$
ωN		$\frac{[(D-3F)m-6M]^2}{16M^2}$	0	$-\frac{((3F-2D)m+6M)}{24\sqrt{3}M^2} *$ ((D+3F)m+6M)	$-\frac{\sqrt{3}((F-D)m+2M)(Fm+2M)}{8M^2}$
ϕN			0	$-\frac{((D+3F)m+6M)^2}{(24\sqrt{6}M^2)}$	$-\sqrt{\frac{3}{2}}\frac{((F-D)m+2M)^2}{8M^2}$
$K^*\Lambda$				$\frac{((D-3F)m-6M)^2}{48M^2}$	$-\frac{((D-3F)m-6M)((D+F)m+2M)}{16M^2}$
$K^*\Sigma$					$-\frac{((D+F)m+2M)^2}{16M^2}$

s-channel: $V_S^{1/2} = 3C_{ij}^s \left(\frac{g^2}{m_v + 2M_B} \right)$

I=1/2

C_{ij}^s	ρN	ωN	$K^*\Lambda$	$K^*\Sigma$
ρN	$\frac{3\left[(D+F)m-2M\right]^2}{16M^2}$	$\frac{3\sqrt{3}\left[(D+F)m-2M\right]}{8M}$	$\frac{((D+F)m-2M)\left[(D+3F)m-6M\right]}{16M^2}$	$-\frac{3}{16M^2}\left[(D-F)m+2M\right]*$ $\left[(D+F)m-2M\right]$
ωN		$\frac{9}{4}$	$\frac{\sqrt{3}((D+3F)m-6M)}{8M}$	$-\frac{3\sqrt{3}((D-F)m+2M)}{8M}$
$K^*\Lambda$			$\frac{((D+3F)m-6M)^2}{48M^2}$	$-\frac{((D+3F)m-6M)}{16M^2}*$ ((D-F)m+2M)
$K^*\Sigma$				$\frac{3((D-F)m+2M)^2}{16M^2}$