Unitarized Chiral Dynamics in few-body Systems

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Introduction

- Until recently, meson-meson and meson-baryon structure of meson and baryon resonances has been explored extensively using chiral dynamics, e.g. :

$$\underbrace{\sigma(600), f_0(980), a_0(980), \kappa,}_{\text{MM}} \underbrace{\Lambda(1405), \Lambda(1520)}_{\text{MB}}, etc.$$ [1, 2, 3, 4,5]

- Some states in the meson & baryon spectrum, however, could very well possess a more complicated molecular structure

M + MM   M + MB

[1] J. A. Oller, E. Oset, Nucl. Phys. A 620 (1997) 438.
[2] J. A. Oller, Ulf-G. Meissner, Phys. Lett. B 500 (2001) 263-272.
[3] J. A. Oller, E. Oset, J. R. Peláez, Phys. Rev. D 59 074001 (199).
[4] D. Jido, J. A. Oller, E. Oset, A. Ramos, U. G. Meissner, Nucl. Phys. A 725 (2003) 181-200.
[5] L. Roca, Sourav Sarkar, V.K. Magas, E. Oset Phys. Rev. C73, 045208 (2006).

The model

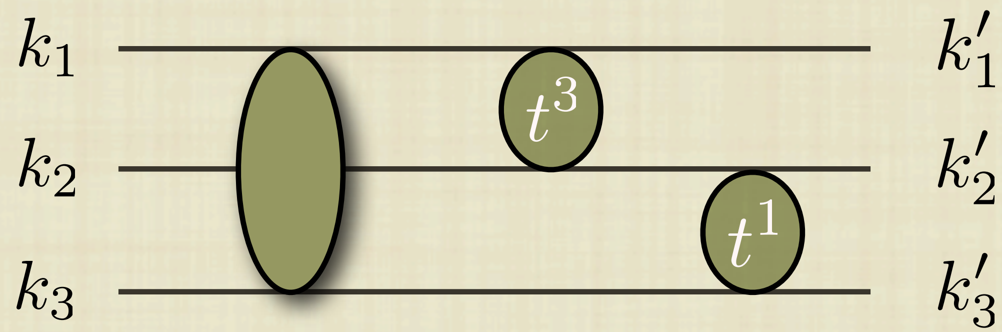
- We solve the Faddeev equations

$$T = T^1 + T^2 + T^3$$

$$T^i = t^i \delta^3(\vec{k}_i{}' - \vec{k}_i) + T_R^{ij} + T_R^{ik}$$

- The T_R^{ij} matrices contain all the possible diagrams where the last two successive interactions are t^i and t^j

$T_R^{13} =$

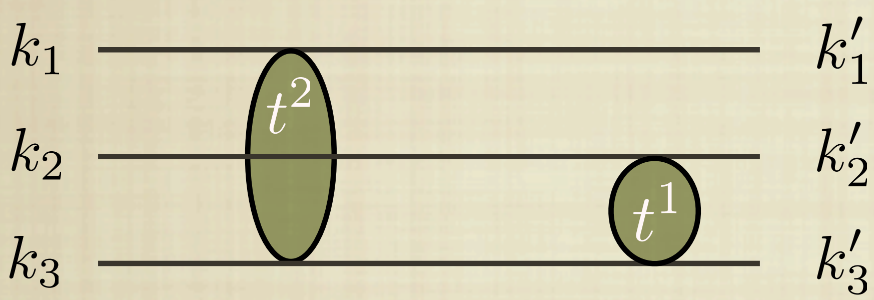


- And they satisfy the equations:

$$\begin{aligned}
T_R^{12} &= t^1 g^{12} t^2 + t^1 \left[G^{121} T_R^{21} + G^{123} T_R^{23}\right] \\
T_R^{13} &= t^1 g^{13} t^3 + t^1 \left[G^{131} T_R^{31} + G^{132} T_R^{32}\right] \\
T_R^{21} &= t^2 g^{21} t^1 + t^2 \left[G^{212} T_R^{12} + G^{213} T_R^{13}\right] \\
T_R^{23} &= t^2 g^{23} t^3 + t^2 \left[G^{231} T_R^{31} + G^{232} T_R^{32}\right] \\
T_R^{31} &= t^3 g^{31} t^1 + t^3 \left[G^{312} T_R^{12} + G^{313} T_R^{13}\right] \\
T_R^{32} &= t^3 g^{32} t^2 + t^3 \left[G^{321} T_R^{21} + G^{323} T_R^{23}\right]
\end{aligned}$$

- t^I is the two body t-matrix $\Rightarrow$ $t = V + V\tilde{g}t$

- g^{IJ} is the three-body Green function.



$$g^{ij}(\vec{k_i}', \vec{k_j}) = \left(\prod_{r=1}^{D} \frac{N_r}{2E_r} \right) \frac{1}{\sqrt{s} - E_i(\vec{k_i}') - E_l(\vec{k_i}' + \vec{k_j}) - E_j(\vec{k_j})}$$

$$N_r = \begin{cases} 1 & \text{meson-meson interaction} \\ 2M_r & \text{meson-baryon interaction} \end{cases}$$

- t^I is the two body t-matrix

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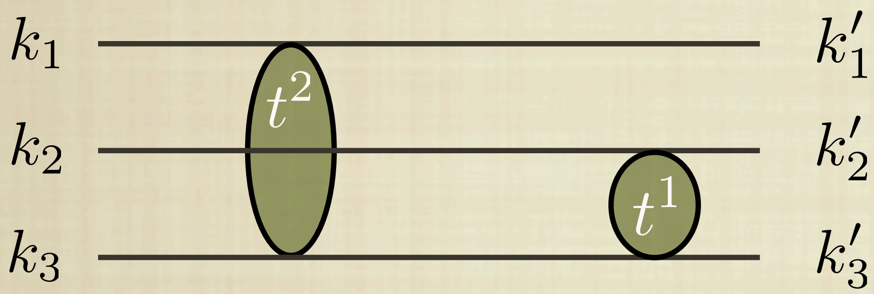

Chiral amplitudes

On-shell part

Off-shell part

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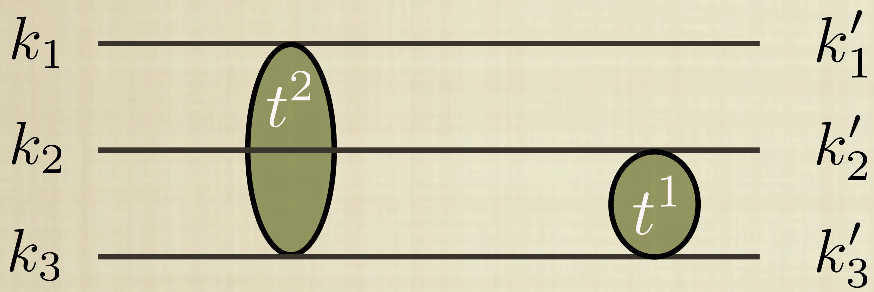

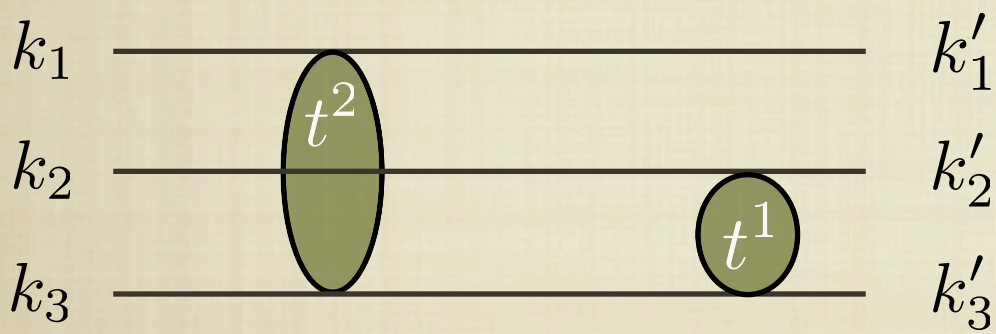

Chiral amplitudes → On-shell part

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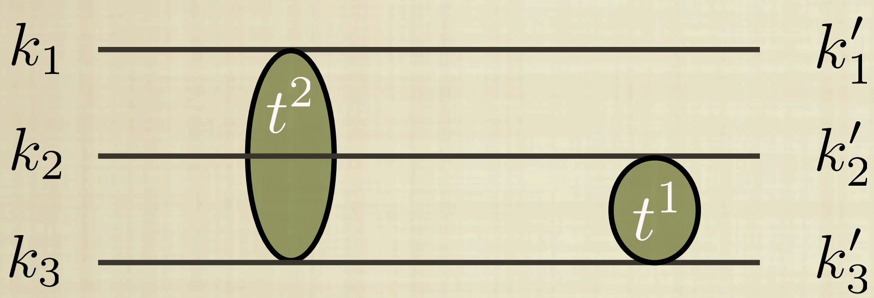

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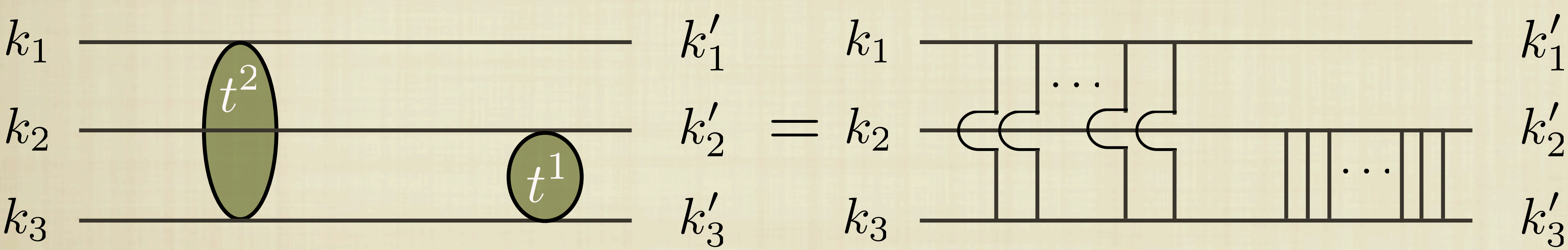

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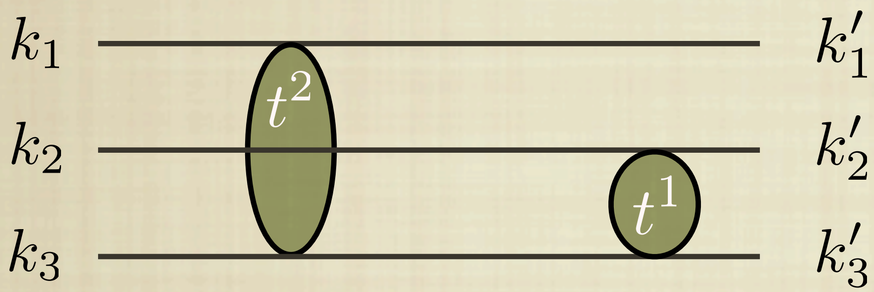

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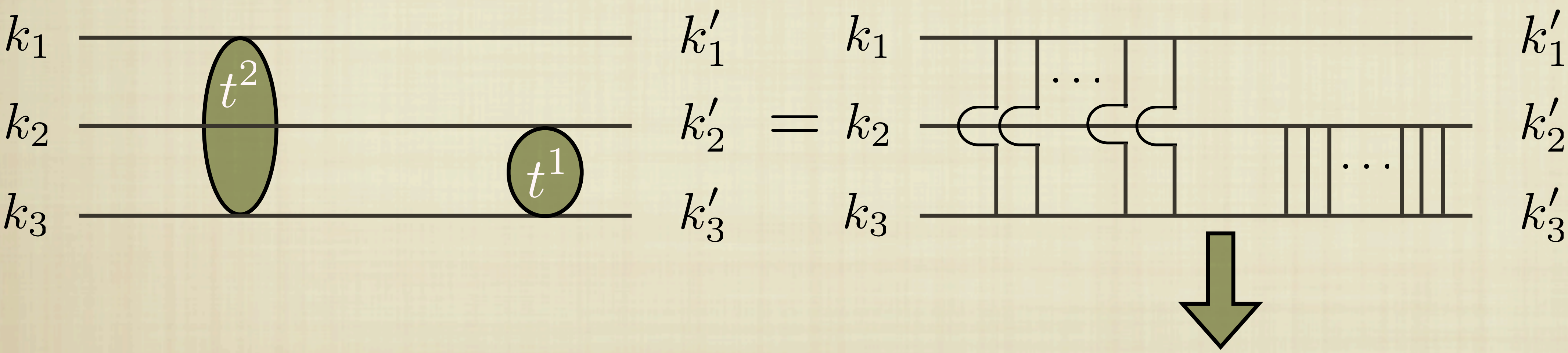

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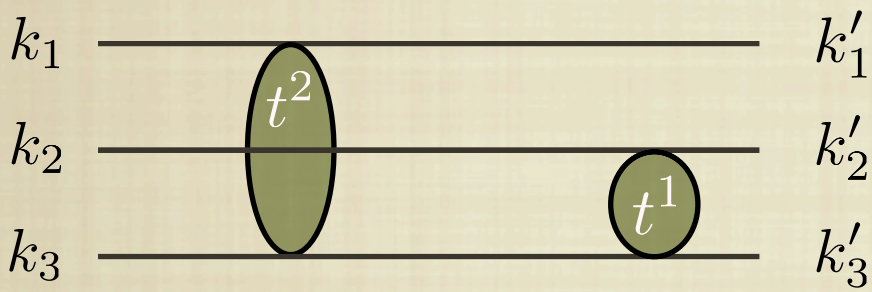

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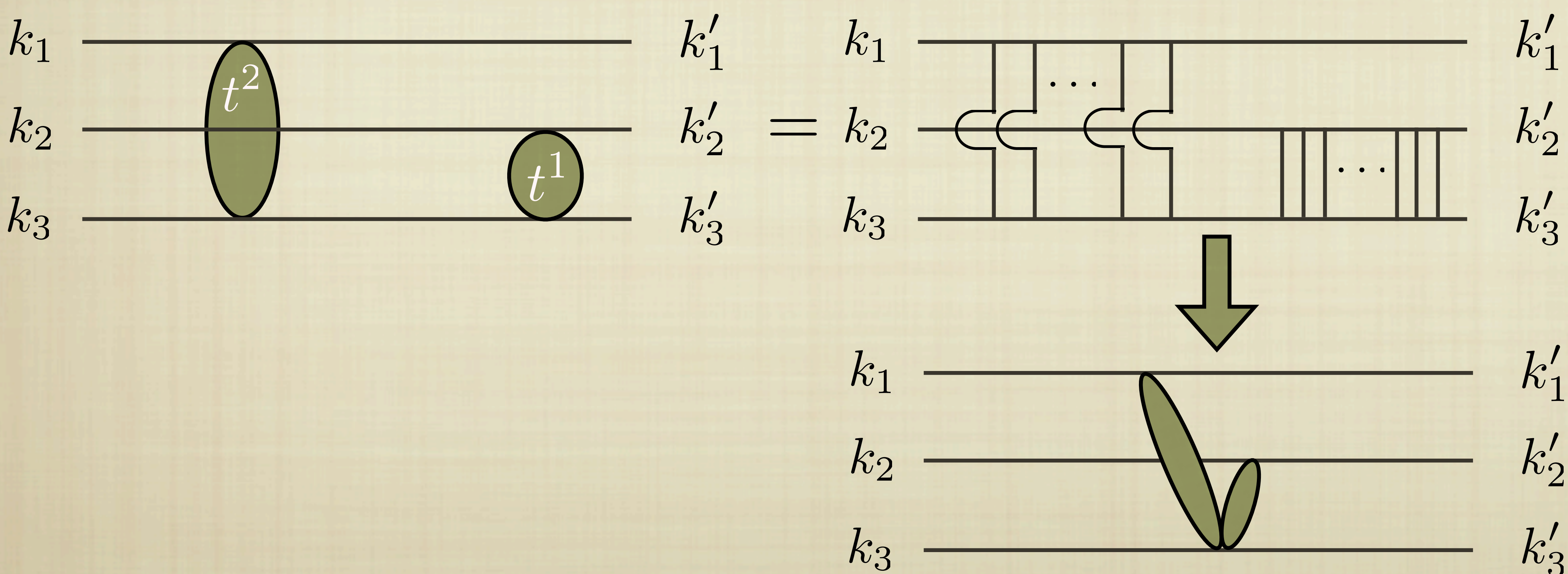

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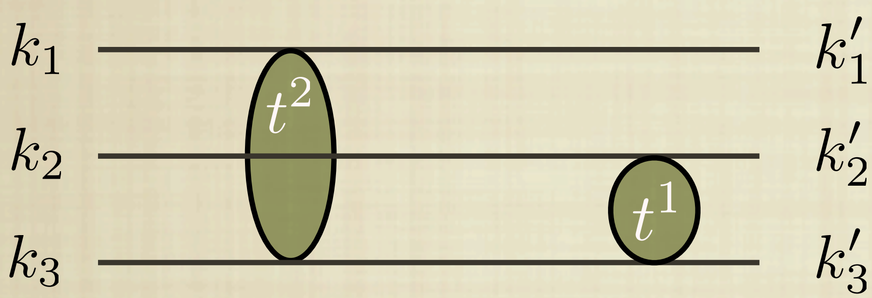

Chiral amplitudes

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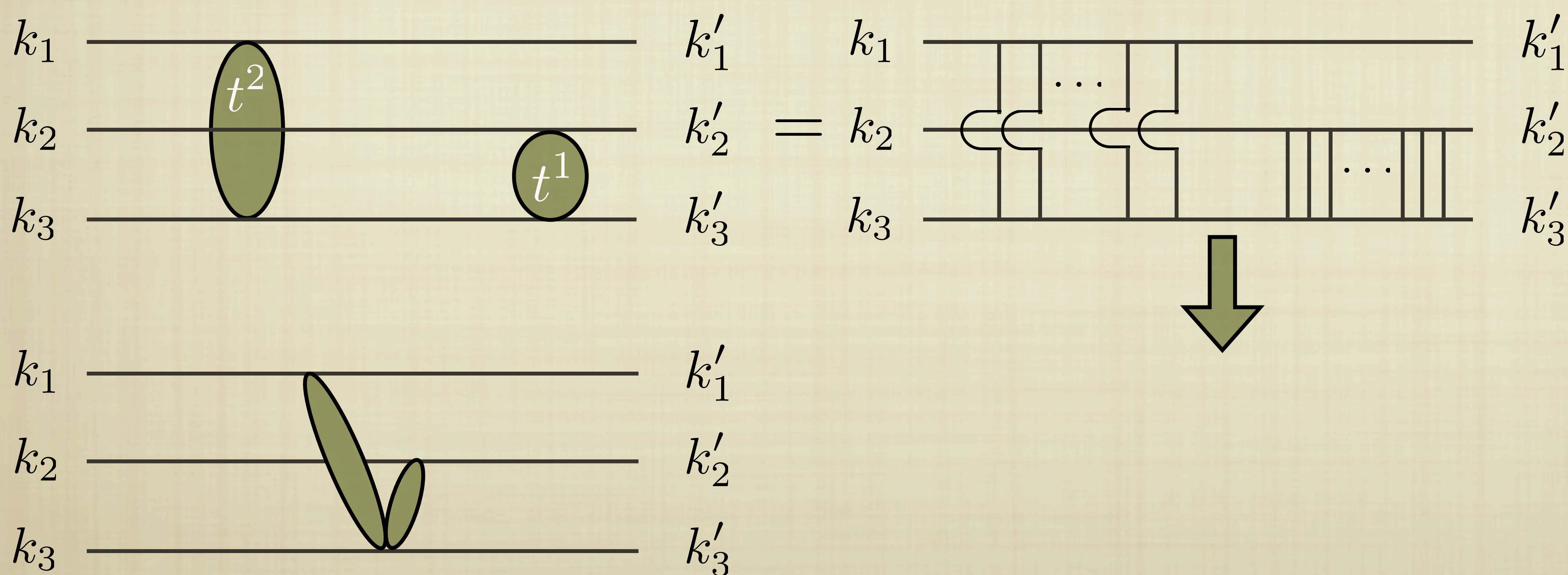

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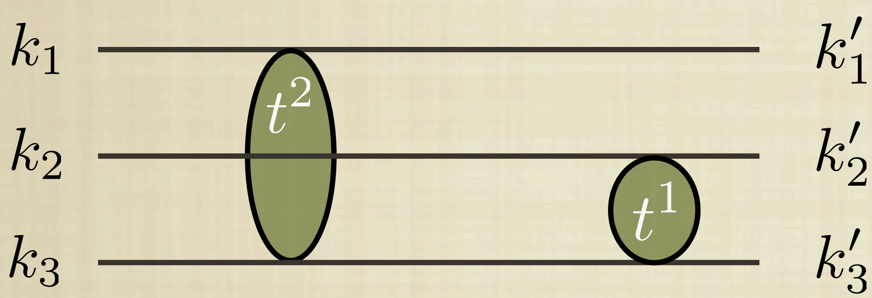

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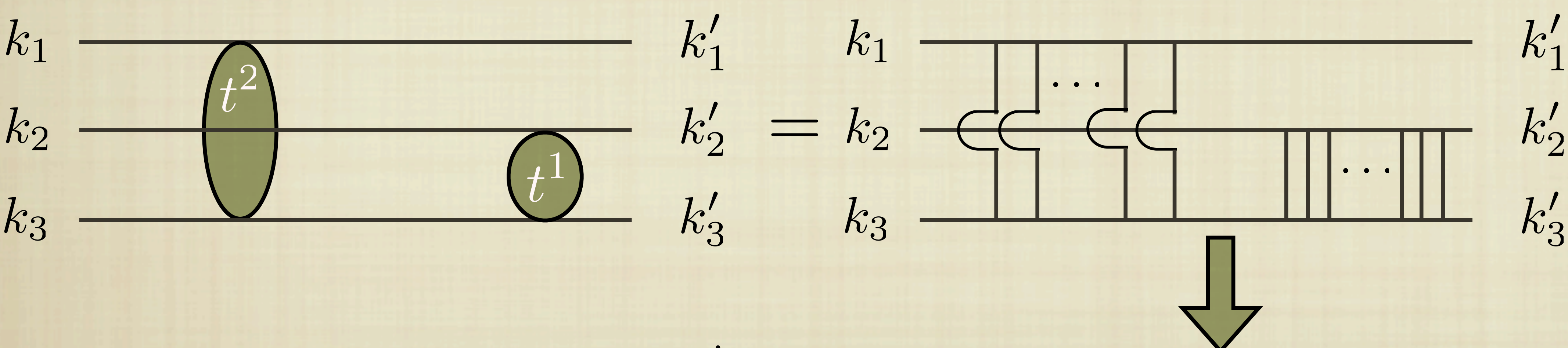

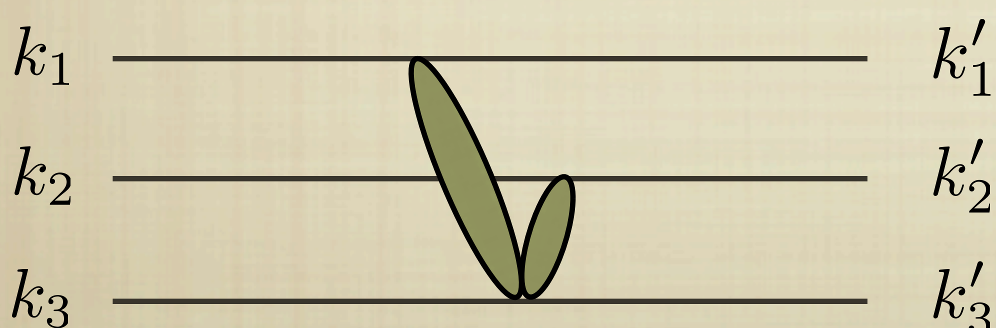

[14] F J. Llanes-Estrada, E. Oset and V. Mateu, Phys. Rev. C 69, 055203 (2004).

- t^I is the two body t-matrix → $t = V + V\tilde{g}t$

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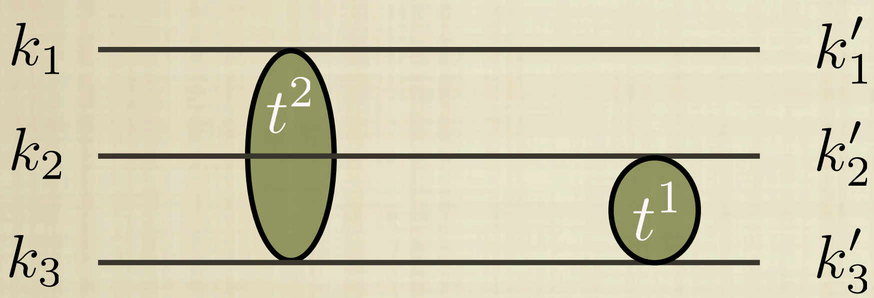

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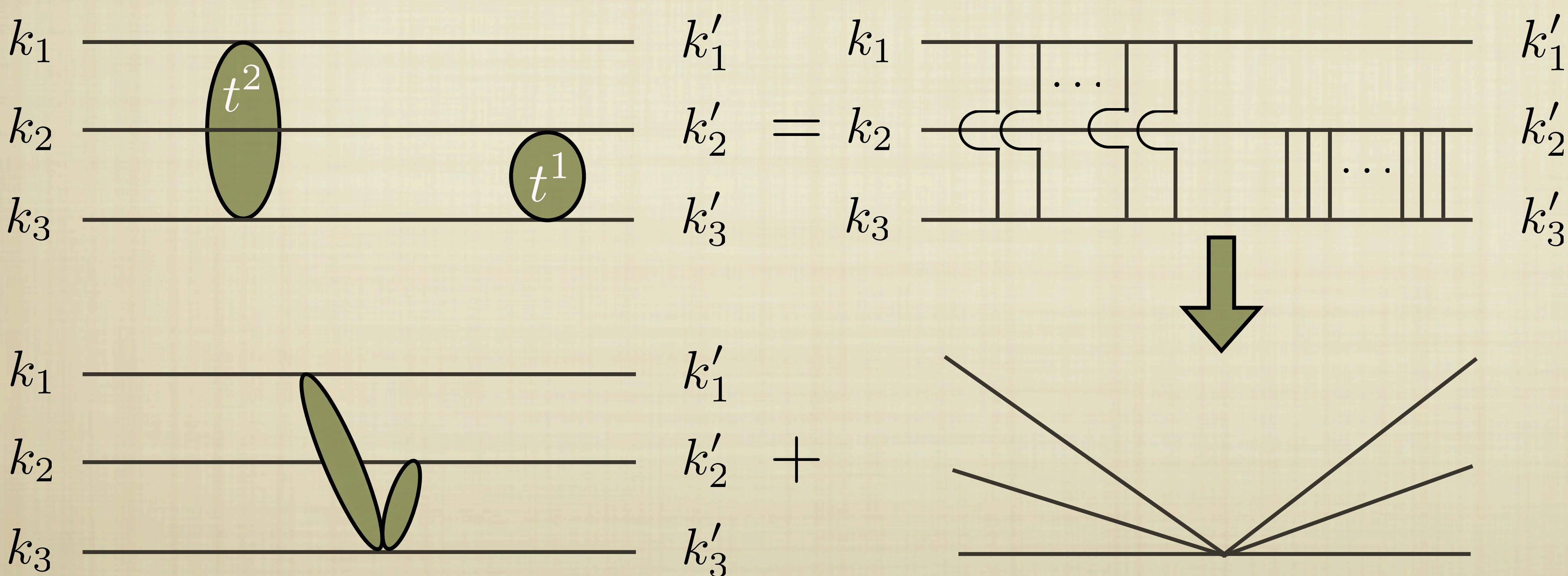

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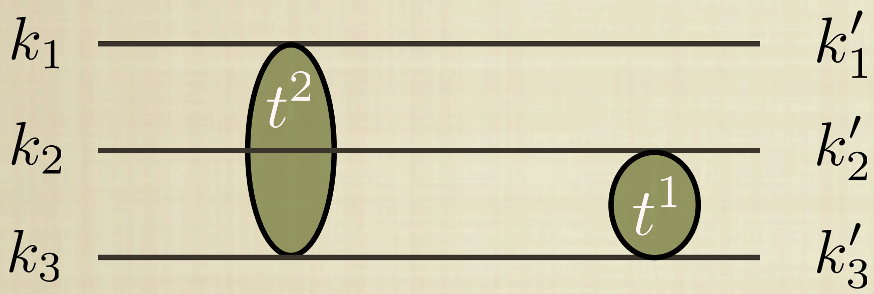

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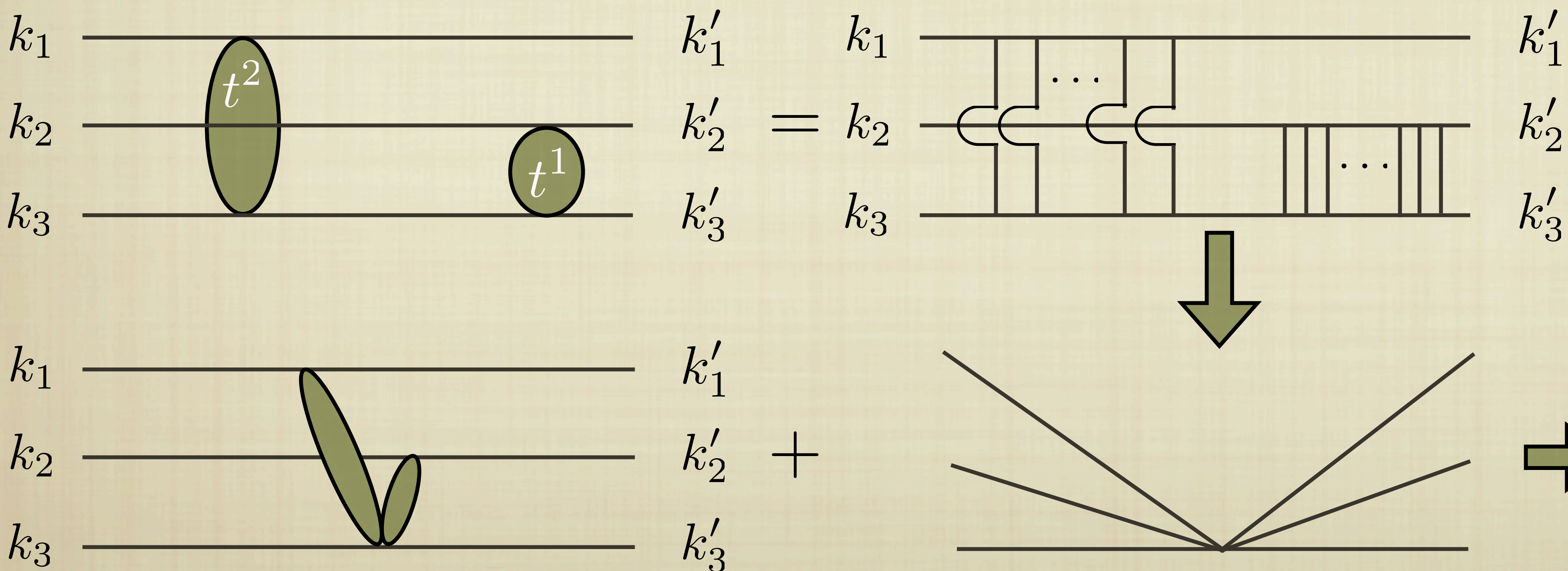


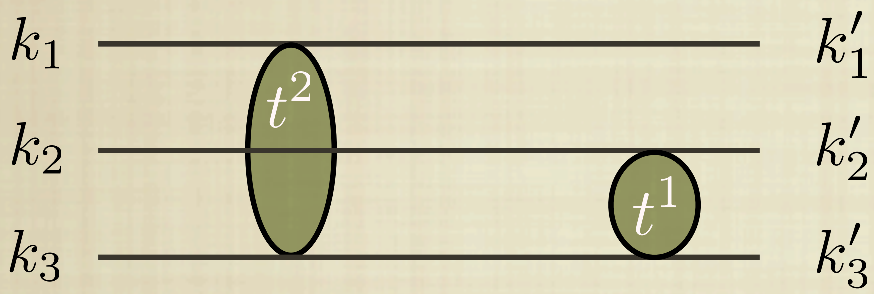
→ cancellation in the SU(3) limit

[14] F J. Llanes-Estrada, E. Oset and V. Mateu, Phys. Rev. C 69, 055203 (2004).

- t^I IS THE TWO BODY t-MATRIX

$$t = V + V\tilde{g}t$$

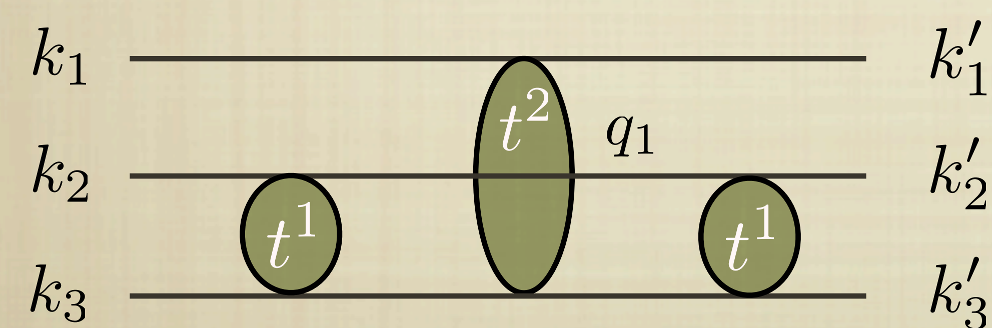
- g^{IJ} IS THE THREE-BODY GREEN



$$g^{ij}(\vec{k}_i{}', \vec{k}_j) = \left(\prod_{r=1}^{D} \frac{N_r}{2E_r}\right) \frac{1}{\sqrt{s} - E_i(\vec{k}_i{}') - E_l(\vec{k}_i{}' + \vec{k}_j) - E_j(\vec{k}_j)}$$

$$N_r = \begin{cases} 1 & \text{meson-meson interaction} \\ 2M_r & \text{meson-baryon interaction} \end{cases}$$

- G^{IJK} IS THE LOOP FUNCTION FOR DIAGRAMS INVOLVING THREE t MATRICES.



$$\int \frac{d^3q_1}{(2\pi)^3} t^1(\sqrt{s_{23}}) g^{12} t^2(q_1^2) g^{21} t^1(\sqrt{s_{23}})$$

$$G^{121} = \int \frac{d^3q_1}{(2\pi)^3} g^{12} t^2(q_1^2) g^{21} [g^{21}(\vec{k}_2', \vec{k}_1)]^{-1} [t^2(\sqrt{s_{23}})]^{-1}$$

$$t^1(\sqrt{s_{23}}) G^{121} t^2(\sqrt{s_{13}}) g^{21}(\vec{k}_2', \vec{k}_1) t^1(\sqrt{s_{23}})$$

Two meson-one baryon systems

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

Two meson-one baryon systems

- $\underbrace{\pi\bar{K}N, \pi\pi\Sigma, \pi\pi\Lambda, \pi\eta\Sigma, \pi\eta\Lambda, \pi K\Xi}$

S-wave

$$J^\pi = 1/2^+$$

Two meson-one baryon systems

- $\pi\bar{K}N, \pi\pi\Sigma, \pi\pi\Lambda, \pi\eta\Sigma, \pi\eta\Lambda, \pi K\Xi$ $\Rightarrow$ Four Σ and two Λ states with $J^P=1/2^+$ in the energy region 1500-1800 MeV.

$\Sigma(1660): \; K^-p \to \pi\pi\Sigma$ $\qquad$ $\Lambda(1600): \; K^-p \to \pi\pi\Lambda$

Two meson-one baryon systems

- $\pi \bar{K} N, \pi\pi\Sigma, \pi\pi\Lambda, \pi\eta\Sigma, \pi\eta\Lambda, \pi K \Xi$ → Four Σ and two Λ states with $J^P=1/2^+$ in the energy region 1500-1800 MeV.

	Γ (PDG) (MeV)	Peak position (this work) (MeV)	Γ (this work) (MeV)
Isospin = 1			
$\Sigma(1560)$	10-100	1590	70
$\Sigma(1620)$	10-100	1630	39
$\Sigma(1660)$	40-200	1656	30
$\Sigma(1770)$	60-100	1790	24
Isospin = 0			
$\Lambda(1600)$	50-250	1568, 1700	60, 136
$\Lambda(1810)$	50-250	1740	20

Two meson-one baryon systems

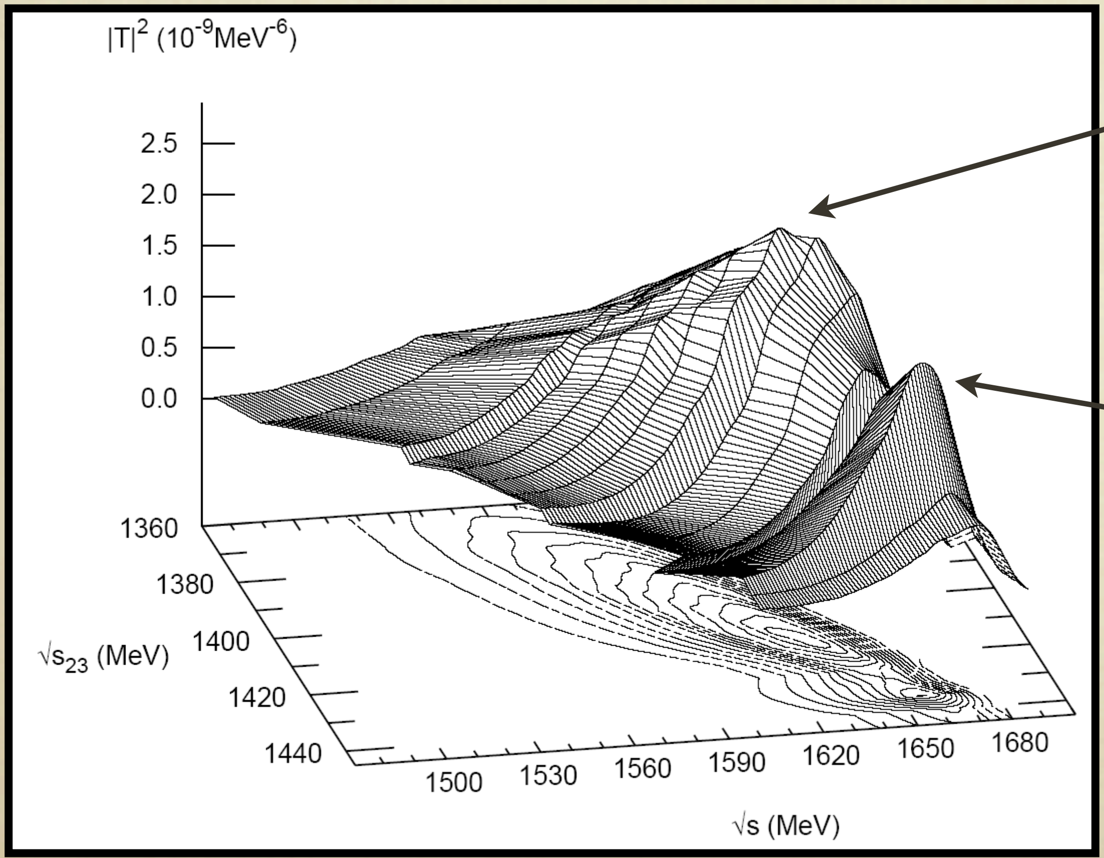
- $\pi\bar{K}N, \pi\pi\Sigma, \pi\pi\Lambda, \pi\eta\Sigma, \pi\eta\Lambda, \pi K\Xi$ → Four Σ and two Λ states with $J^P=1/2^+$ in the energy region 1500-1800 MeV.

Σ(1660)

$$1656 - i30/2\ MeV$$

Σ(1620)

$$1630 - i39/2\ MeV$$



R. Armenteros et al. Nucl. Phys. B 8, 183 (1968).
B. R. Martin et al, Nucl. Phys. B 127, 349 (1977).

Two meson-one baryon systems

- $\pi\bar{K}N, \pi\pi\Sigma, \pi\pi\Lambda, \pi\eta\Sigma, \pi\eta\Lambda, \pi K\Xi$ → Four Σ and two Λ states with $J^P=1/2^+$ in the energy region 1500-1800 MeV.

- $\pi\pi N, \pi K\Sigma, \pi K\Lambda, \pi\eta N, K\bar{K}N$ → N*(1710) with 40-90% branching ratio to $\pi\,\pi\,\mathrm{N}$

Two meson-one baryon systems

- $\pi\bar{K}N, \pi\pi\Sigma, \pi\pi\Lambda, \pi\eta\Sigma, \pi\eta\Lambda, \pi K\Xi$ $\Rightarrow$ Four Σ and two Λ states with $J^P=1/2^+$ in the energy region 1500-1800 MeV.

- $\pi\pi N, \pi K\Sigma, \pi K\Lambda, \pi\eta N, K\bar{K}N$ $\Rightarrow$ N*(1710) with 40-90% branching ratio to $\pi\pi N$

	Γ (PDG) (MeV)	Peak position (this work) (MeV)	Γ (this work) (MeV)
N*(1710)	50-250	1704	375

Two meson-one baryon systems

- $\pi\bar{K}N, \pi\pi\Sigma, \pi\pi\Lambda, \pi\eta\Sigma, \pi\eta\Lambda, \pi K\Xi$ → Four Σ and two Λ states with $J^P=1/2^+$ in the energy region 1500-1800 MeV.

- $\pi\pi N, \pi K\Sigma, \pi K\Lambda, \pi\eta N, K\bar{K}N$ → N*(1710) with 40-90% branching ratio to $\pi\pi N$

	Γ (PDG) (MeV)
N*(1710)	50-250
N*(2100)	50-360
Δ(1750)	50-300
Δ(1910)	190-270

Two meson-one baryon systems

- $\pi \bar{K} N, \pi\pi\Sigma, \pi\pi\Lambda, \pi\eta\Sigma, \pi\eta\Lambda, \pi K \Xi$ $\Longrightarrow$ Four Σ and two Λ states with $J^P = 1/2^+$ in the energy region 1500-1800 MeV.

- $\pi\pi N, \pi K \Sigma, \pi K \Lambda, \pi\eta N, K \bar{K} N$ $\Longrightarrow$ N*(1710) with 40-90% branching ratio to $\pi\,\pi\,\mathrm{N}$

	Γ (PDG) (MeV)
N*(1710)	50-250
N*(2100)	50-360
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Experimental amplitudes

Two meson-one baryon systems

- $\pi\bar{K}N, \pi\pi\Sigma, \pi\pi\Lambda, \pi\eta\Sigma, \pi\eta\Lambda, \pi K\Xi$ → Four Σ and two Λ states with $J^P=1/2^+$ in the energy region 1500-1800 MeV.

- $\pi\pi N, \pi K\Sigma, \pi K\Lambda, \pi\eta N, K\bar{K}N$ → N*(1710) with 40-90% branching ratio to $\pi\pi N$

	Γ (PDG) (MeV)	Peak position (this work) (MeV)	Γ (this work) (MeV)	
N*(1710)	50-250	1704	375	
N*(2100)	50-360	2080	54	
N*(1920)	?	1924	20	predicted in Phys.Rev.C78,035203 (2008)
Δ(1910)	190-270	2126	42	

Two meson-one baryon systems

- $\pi\bar{K}N, \pi\pi\Sigma, \pi\pi\Lambda, \pi\eta\Sigma, \pi\eta\Lambda, \pi K\Xi$ → Four Σ and two Λ states with $J^P=1/2^+$ in the energy region 1500-1800 MeV.
- $\pi\pi N, \pi K\Sigma, \pi K\Lambda, \pi\eta N, K\bar{K}N$ → N*(1710), N*(2100), N*(1920), Δ(1910). No signal for Roper and Δ(1750).
- πKN → study of the possibility that the Θ^+ could be a πKN bound state.

Two meson-one baryon systems

- $\pi\bar{K}N, \pi\pi\Sigma, \pi\pi\Lambda, \pi\eta\Sigma, \pi\eta\Lambda, \pi K\Xi$ $\rightarrow$ Four Σ and two Λ states with $J^P=1/2^+$ in the energy region 1500-1800 MeV.

- $\pi\pi N, \pi K\Sigma, \pi K\Lambda, \pi\eta N, K\bar{K}N$ $\rightarrow$ N*(1710), N*(2100), N*(1920), Δ(1910). No signal for Roper and Δ(1750).

- πKN $\rightarrow$ study of the possibility that the Θ^+ could be a πKN bound state.

$\downarrow$

we do not find any signal around 1520 MeV but we obtain a peak around 1700 MeV with 200 MeV of width.

Three-meson systems

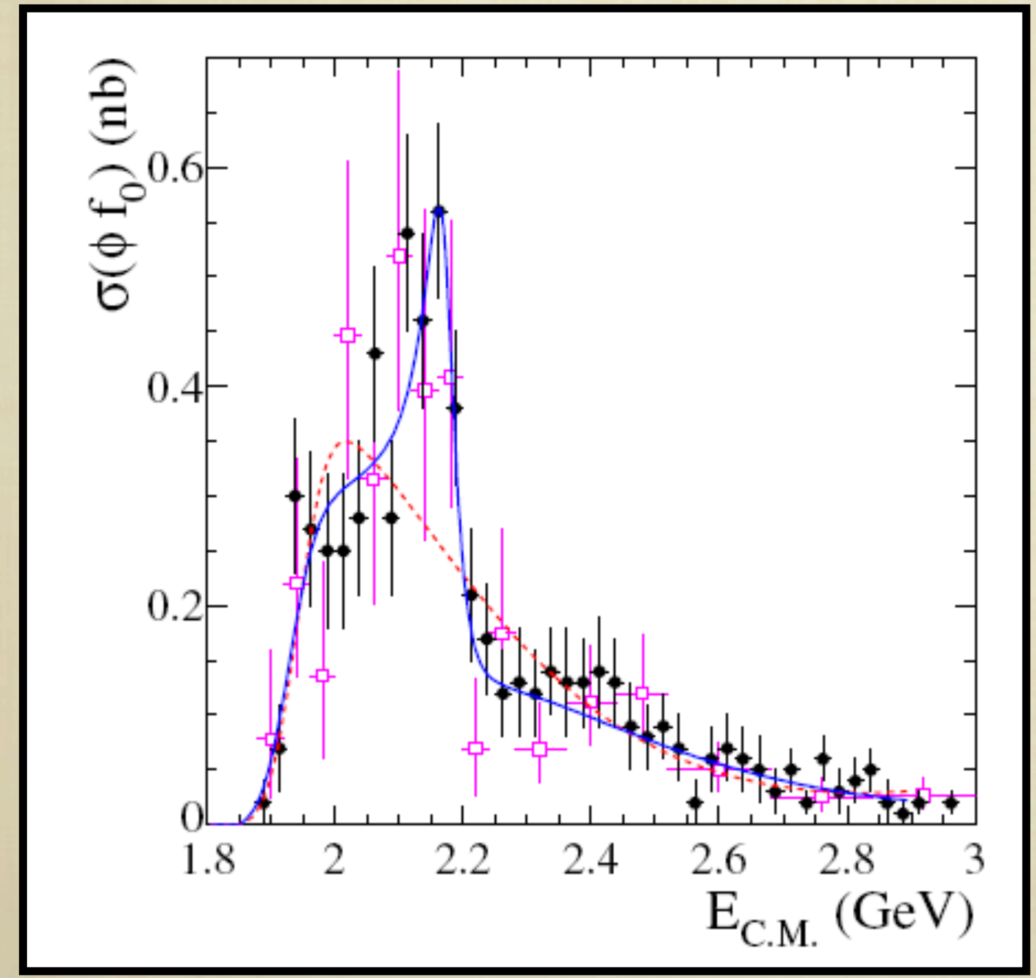
- $\phi K\bar{K}$, $\phi\pi\pi$

Three-meson systems

- $\phi K\bar{K}$, $\phi\pi\pi$

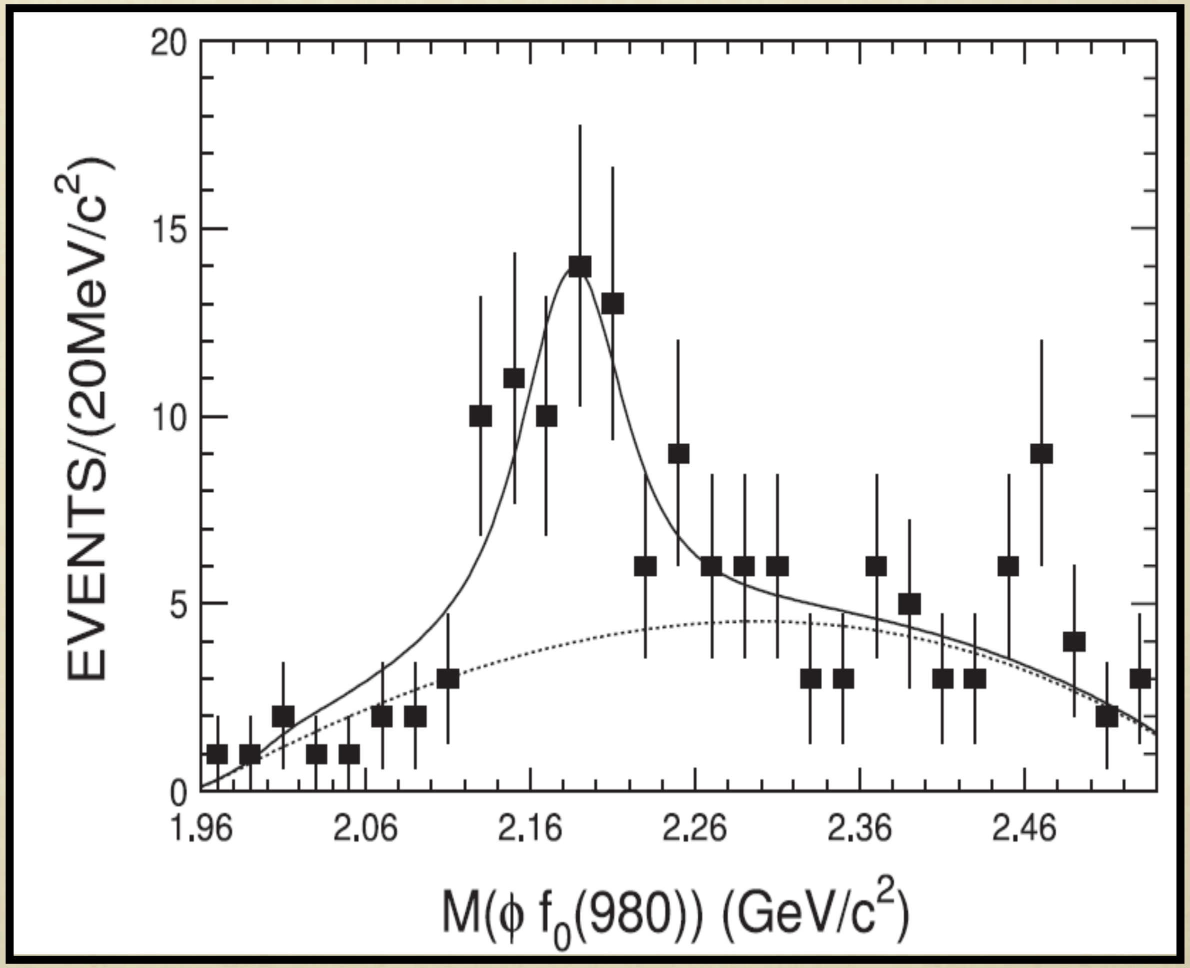
BaBar

$$e^+e^- \rightarrow \phi f_0(980)$$



BES

$$J/\Psi \rightarrow \eta\phi f_0(980)$$



Three-meson systems

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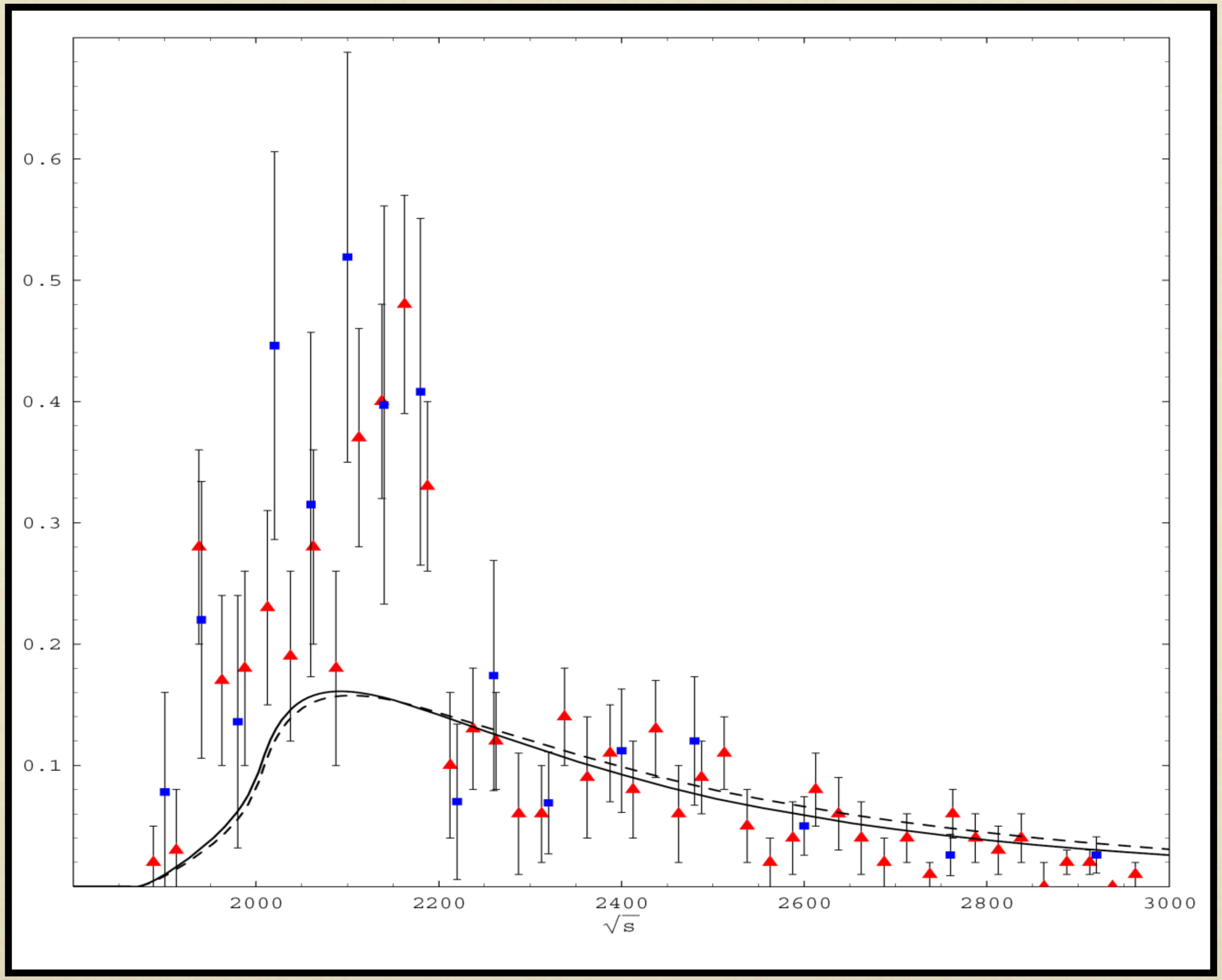
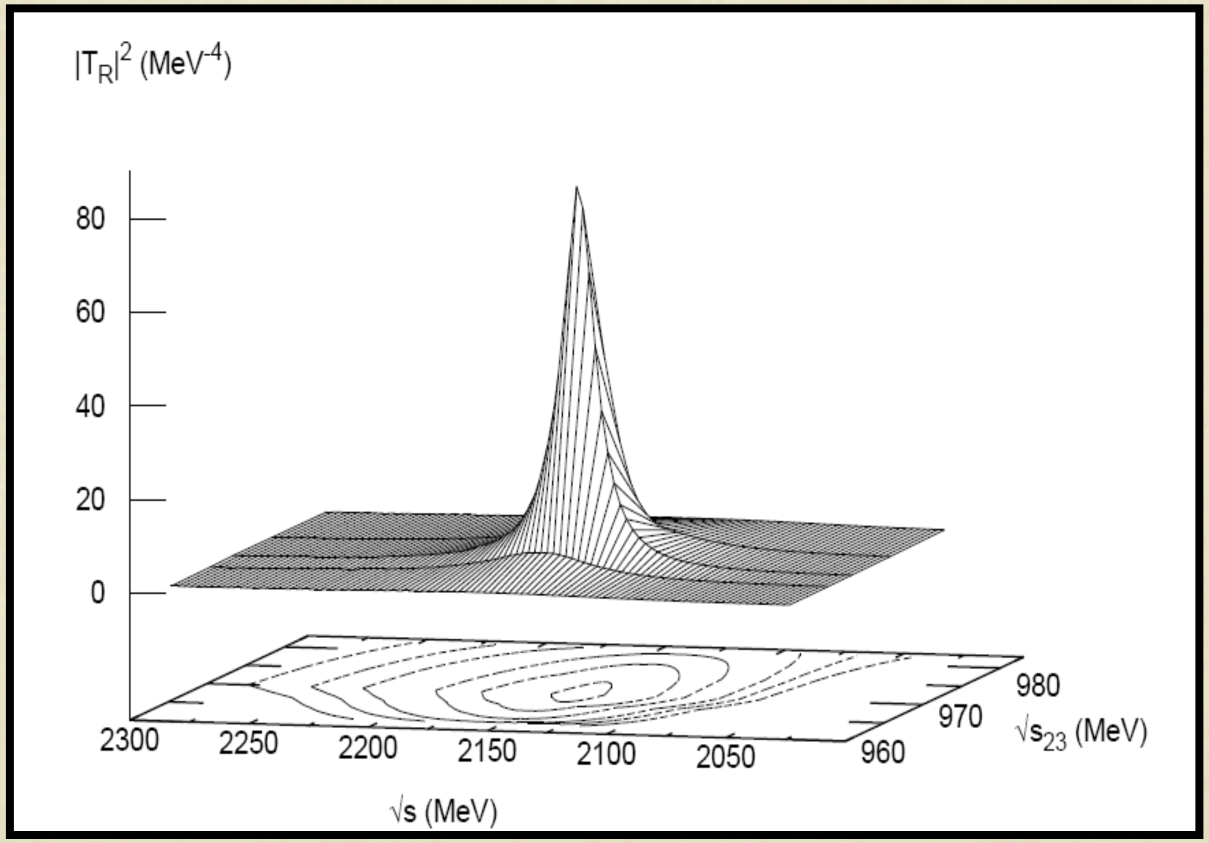


*see a review on different studies (for example) : "New hadron states", Shi-Lin Zhu , Int.J.Mod.Phys.E17:283-322,2008; e-Print: hep-ph/0703225

Three-meson systems

- $\phi K\bar{K}$, $\phi\pi\pi$



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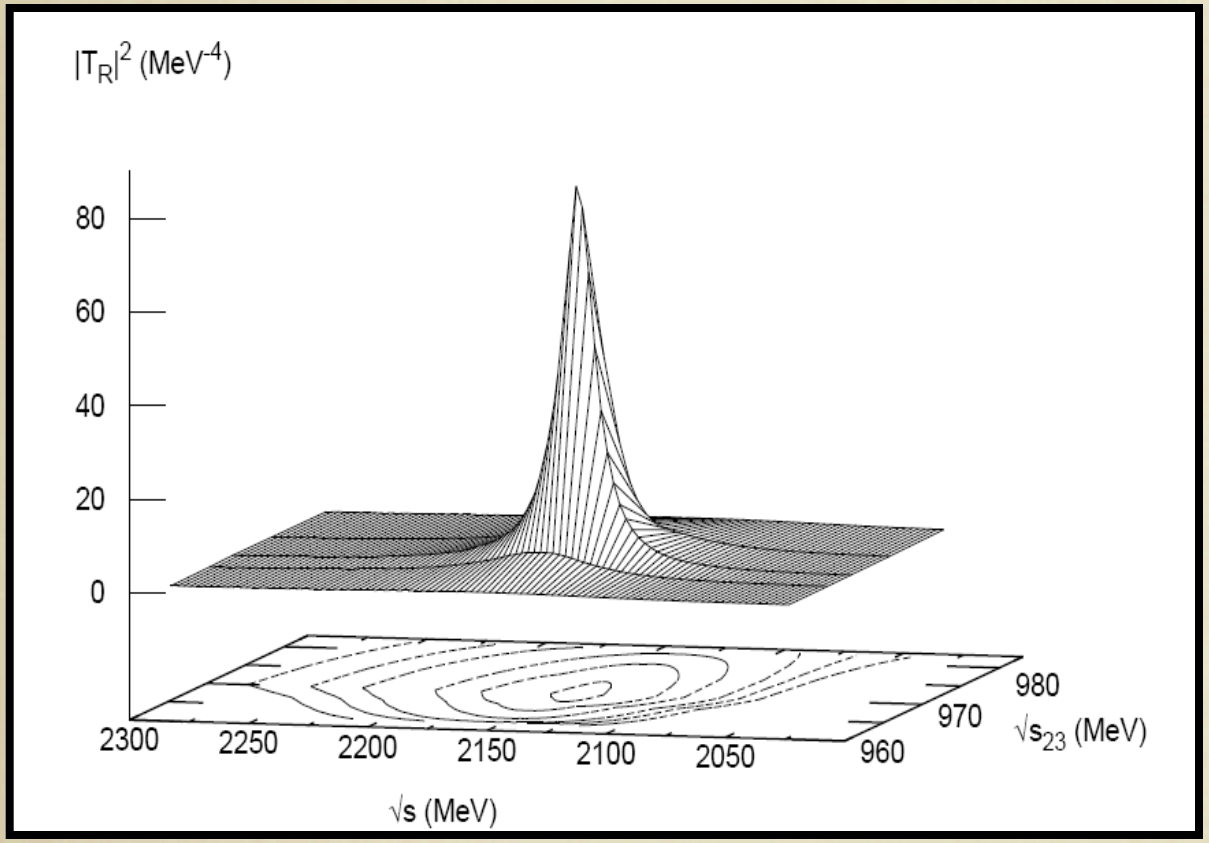

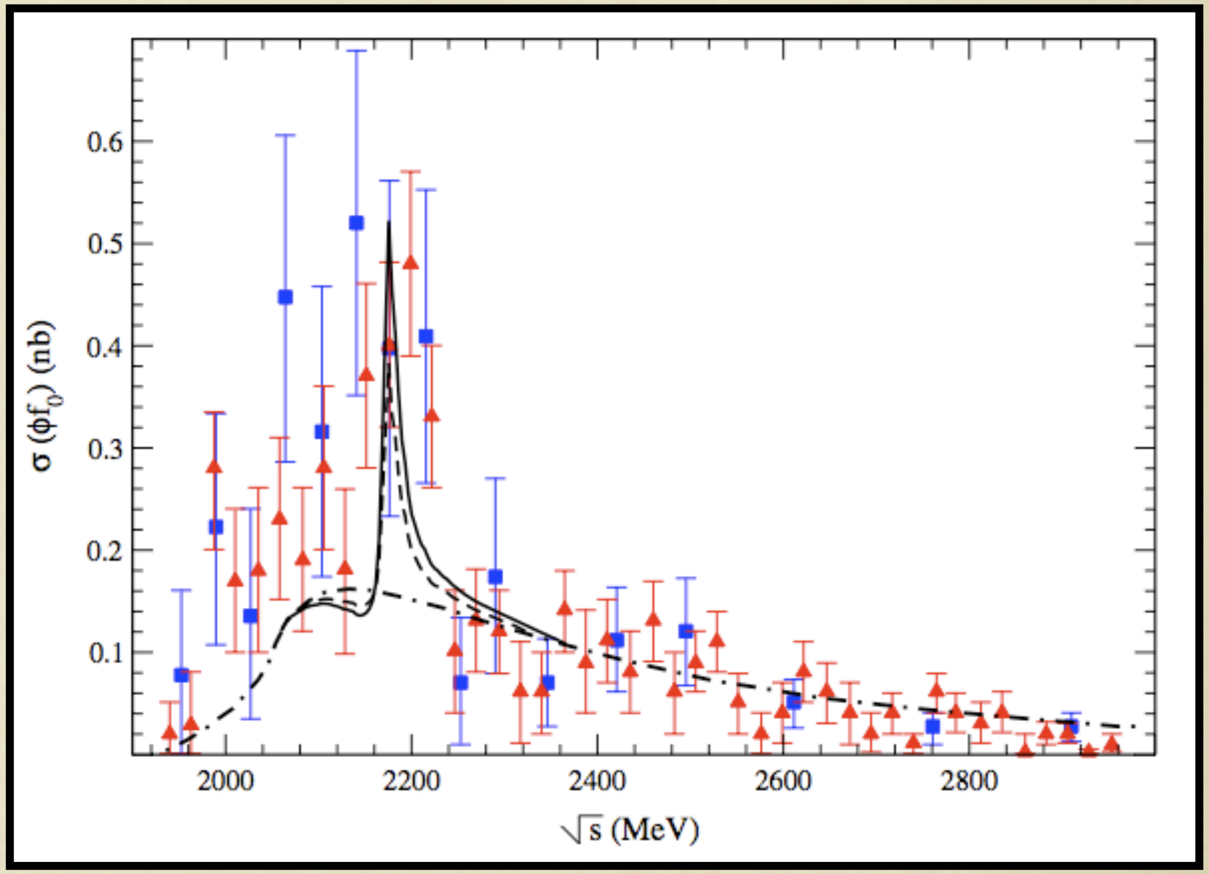

$$T_{pw}^{\phi f_0}[1 + G_{\phi f_0} T_{\phi f_0}]$$

Summary and Future plans

- We have obtained four Σ's and two Λ's resonances in the $\pi\bar{K}N$, which correspond to all the 1/2+ Σ and Λ states in the energy region 1500-1870.
- We observed the N*(1710), N*(2100), Δ(1910) in the $\pi\pi$N system and coupled channels and a possible N*(1910) with $J^P=1/2^+$ in the $K\bar{K}N$ system .
- We have studied the three-meson systems, $\phi K\bar{K}$, $\phi\pi\pi$, where we got the resonance X(2175) .
- A broad bump is obtained in the study of the πKN system around 1700 MeV.
- In the $J/\psi K\bar{K}$, $J/\psi\pi\pi$ systems we obtain the Y(4260).
- Study of the systems $\omega\pi\pi, \rho\pi\pi, K^*\pi K, etc.$, to get the low-lying vector resonances as w(1420), w(1650),etc.

And many more!!