Exotic hadrons in the NπK system and coupled channels

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HYPX 2009, Tokai, 15 september 2009

Why study the NπK system?

- A peak in the K^+n invariant mass in the $\gamma\, n \to K^+K^-n$ reaction at the Spring8/Osaka pentaquark

- Chiral Lagrangians: K^+N interaction is repulsive.

$$\downarrow$$

$$\pi K N$$

- Some investigations have already been done and the results do not look promising[1,2]

[1] P. Bicudo, G. M. M. Marques, Phys. REV. D 69 011503 (2004).
[2] Felipe J. Llanes-Estrada, E. Oset, V. Mateu, Phys. Rev. C 69 055203 (2004).

The model

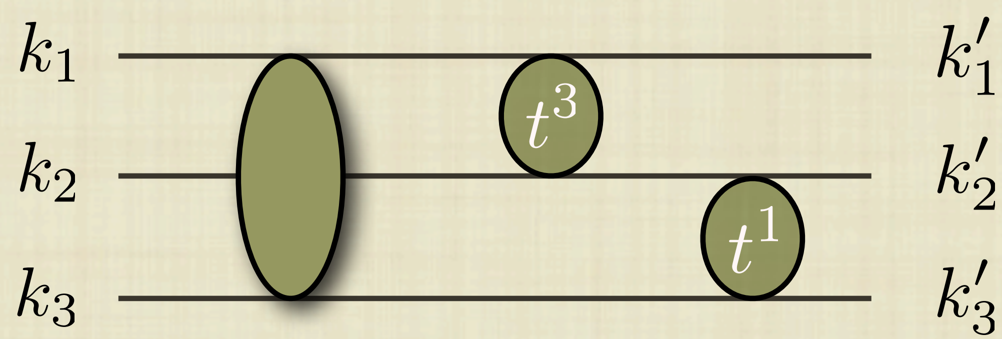
- We solve the Faddeev equations

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

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

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

$$T_R^{13} =$$



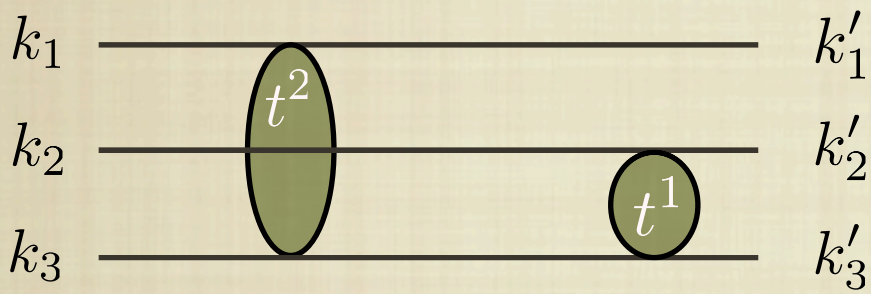
- And they satisfy the equations:

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

- t^I IS THE TWO BODY t-MATRIX

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

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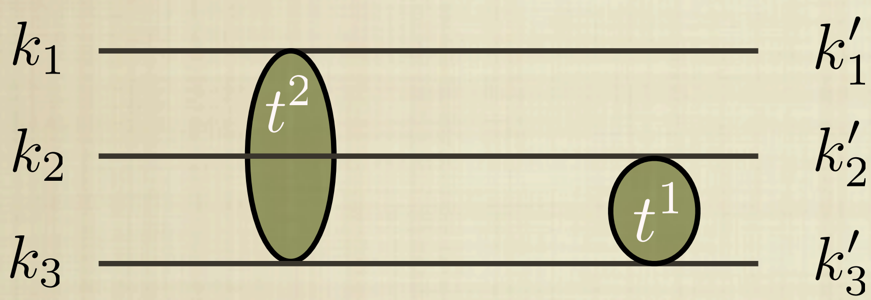

Chiral amplitudes → On-shell part

Chiral amplitudes → Off-shell part

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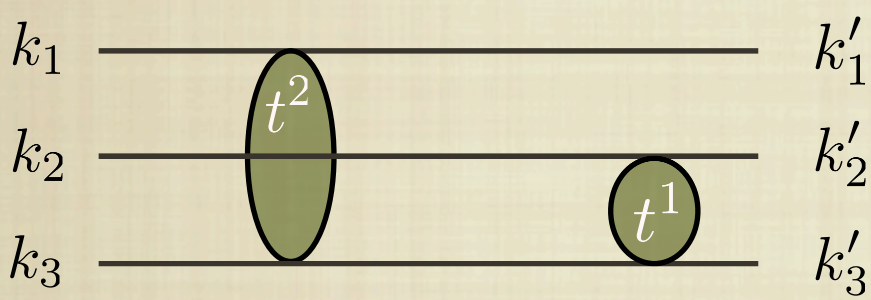

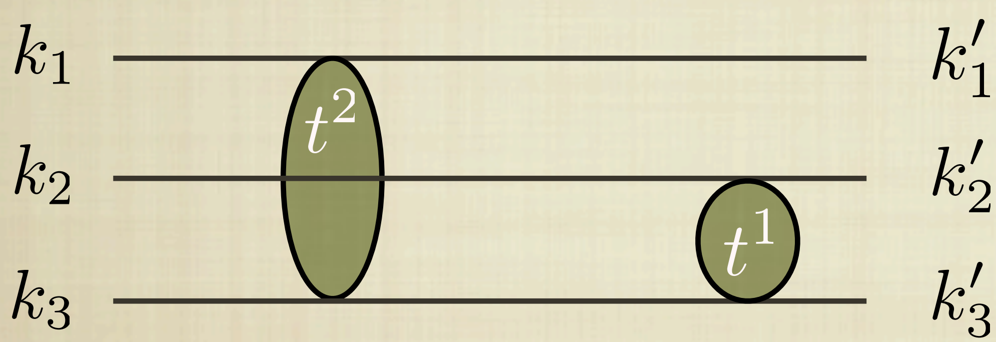

CHIRAL AMPLITUDES → ON-SHELL PART

CHIRAL AMPLITUDES → OFF-SHELL PART

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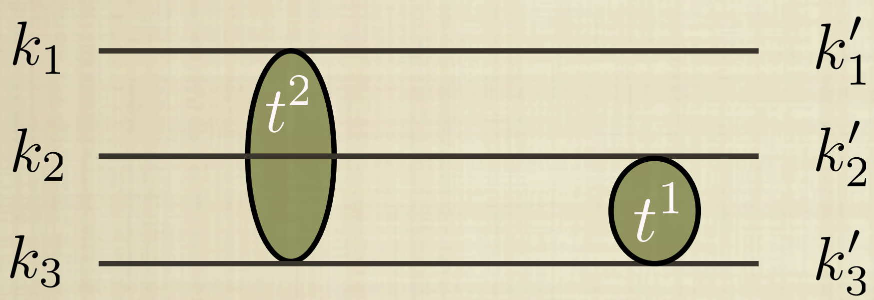
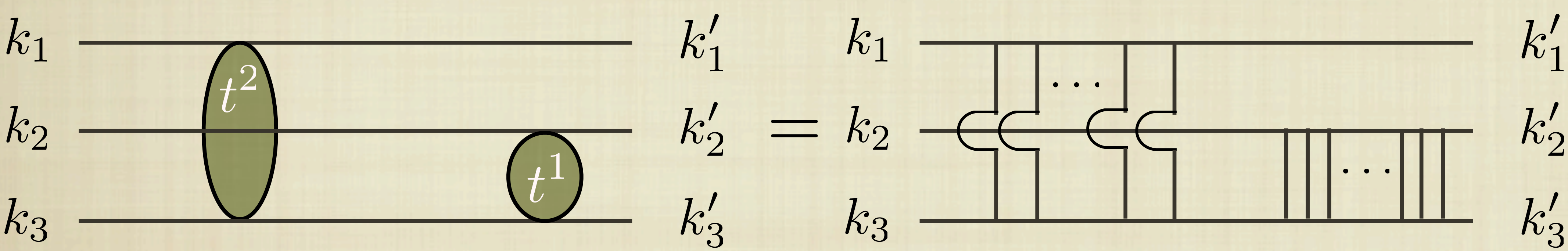


Chiral amplitudes

On-shell part

Off-shell part



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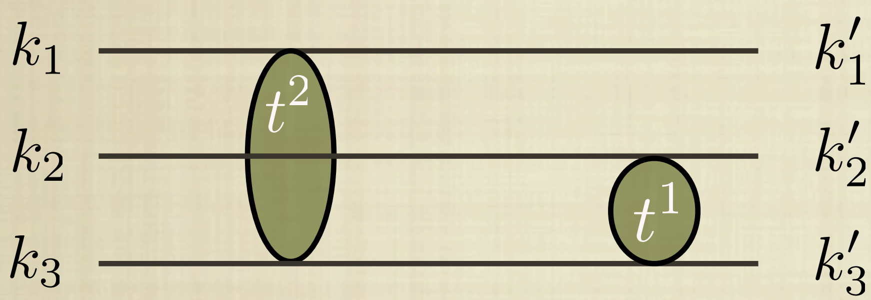

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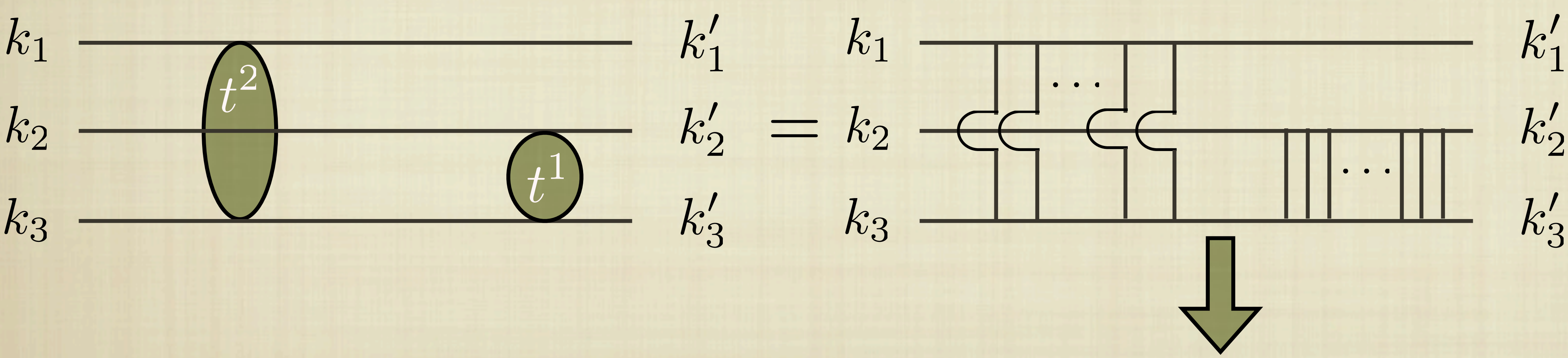

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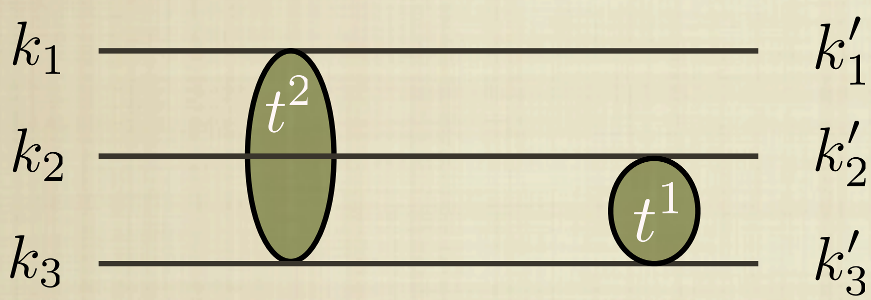

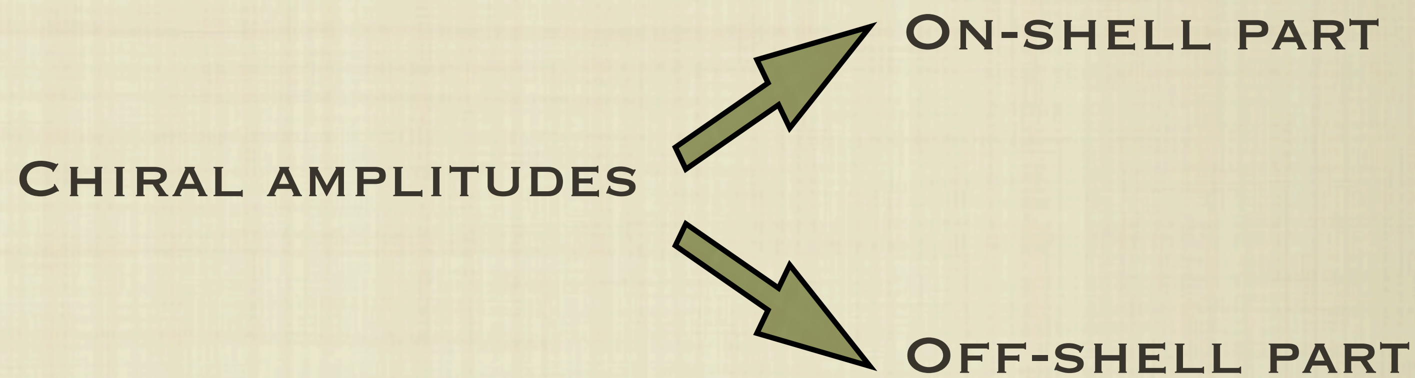

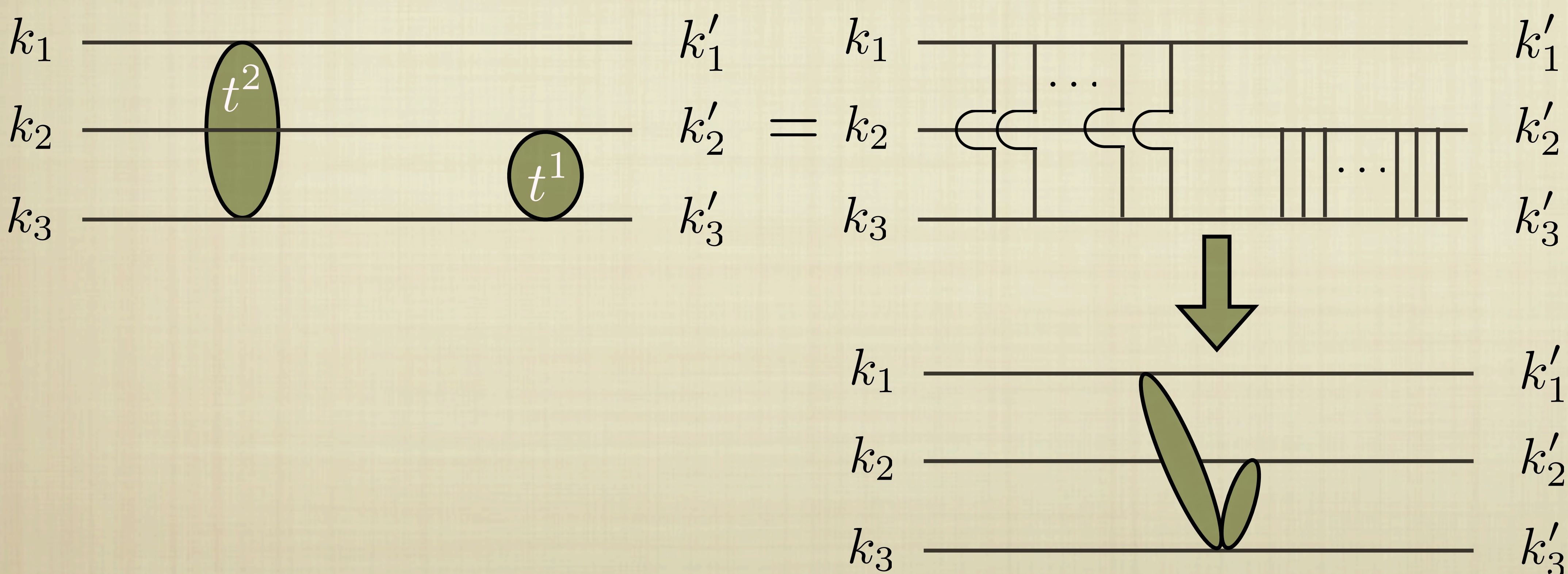

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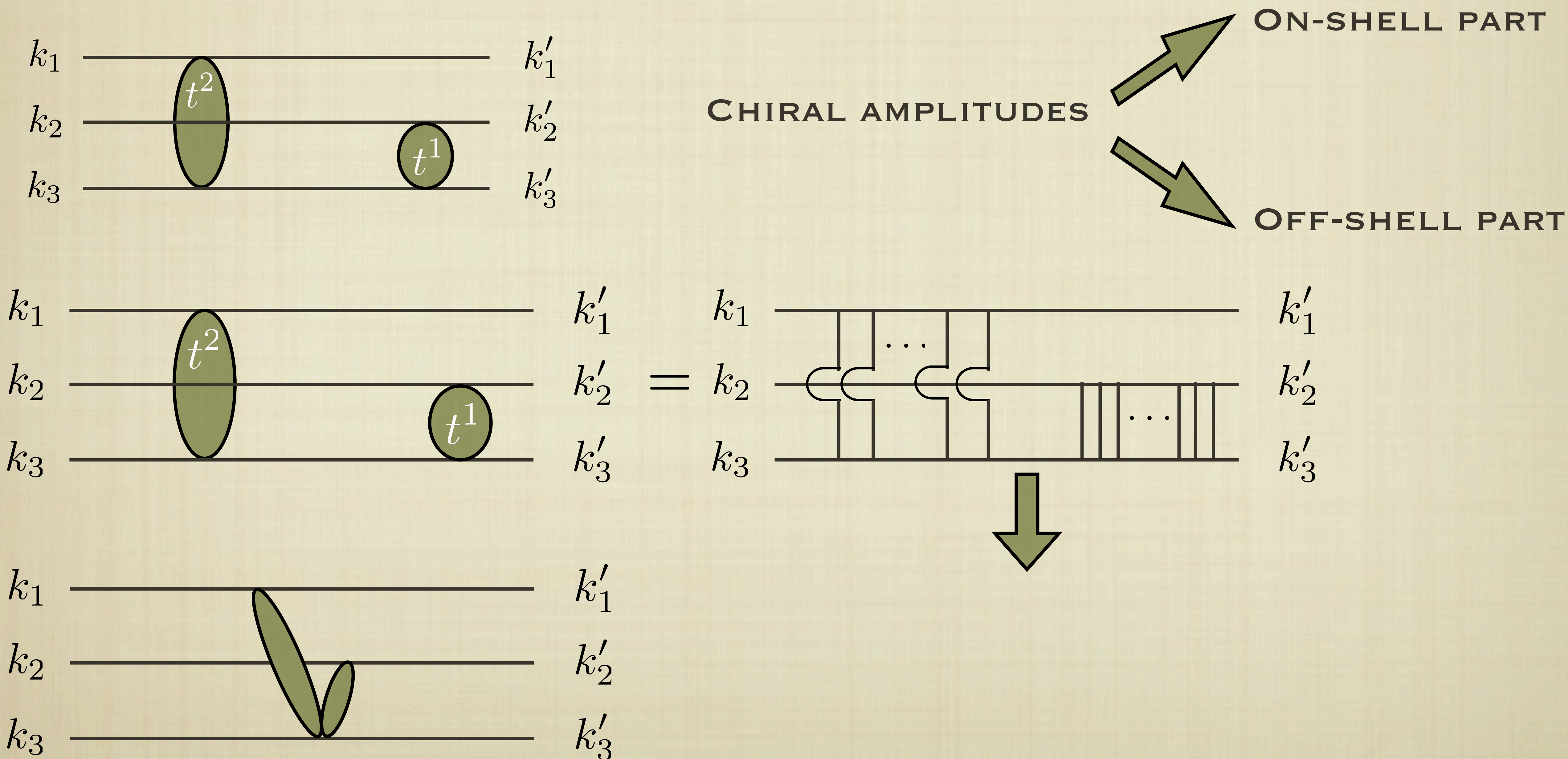

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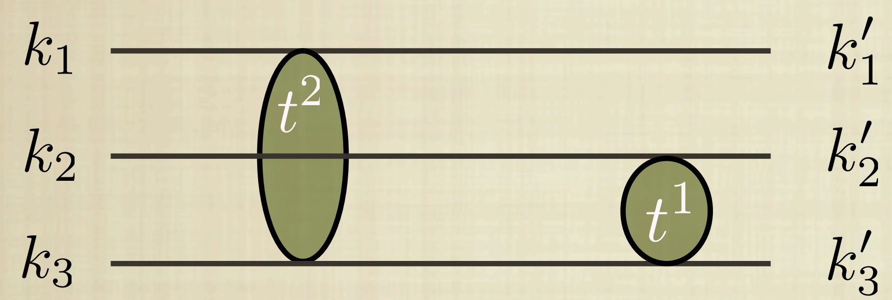

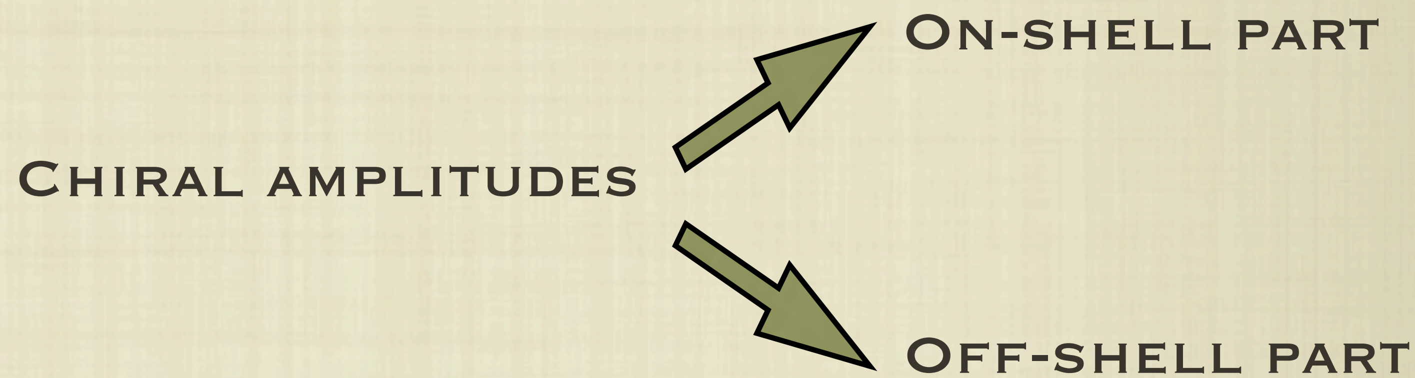

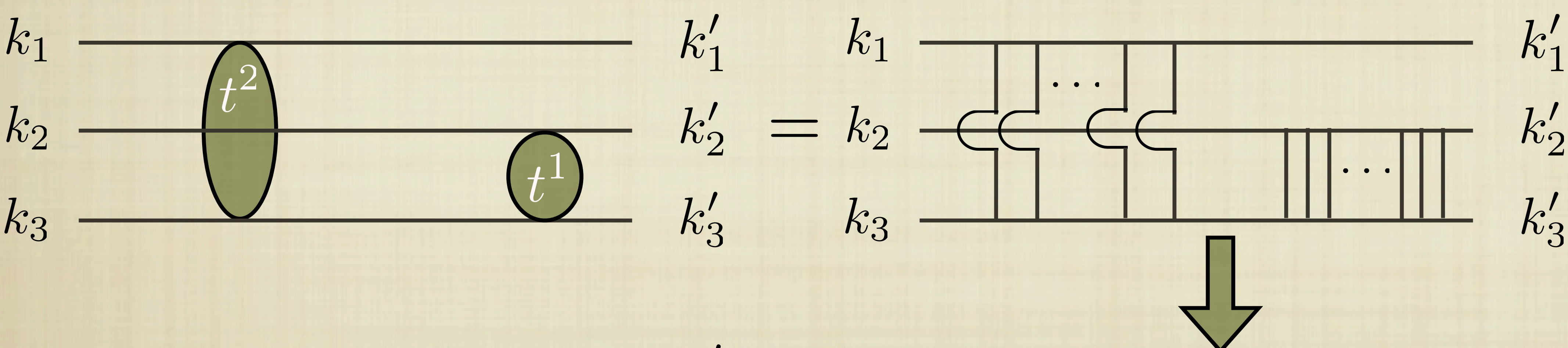

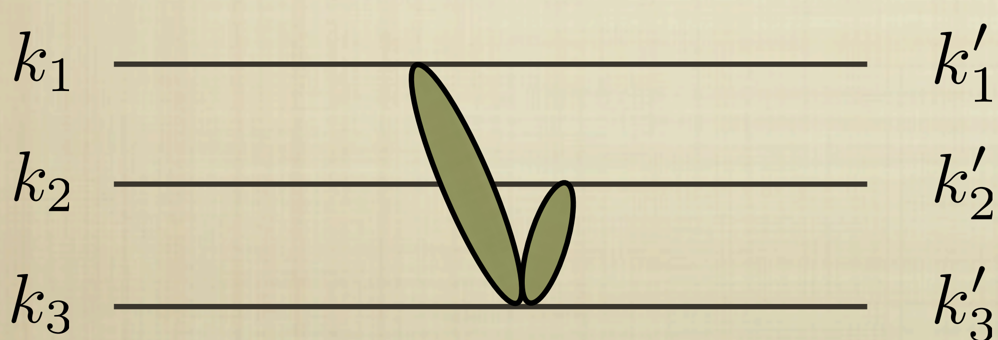

[14] F J. Llanes-Estrada, E. Oset and V. Mateu, Phys. Rev. C 69, 055203 (2004).

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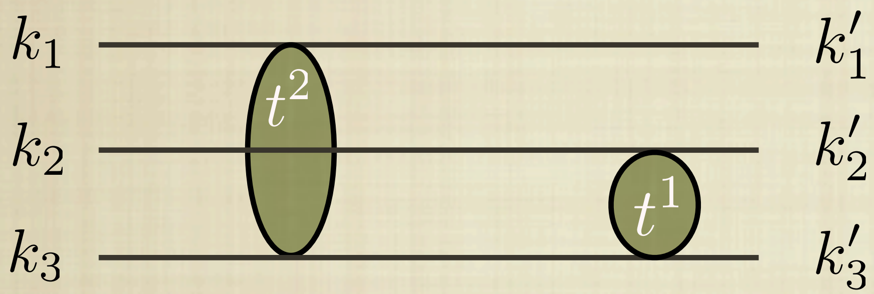
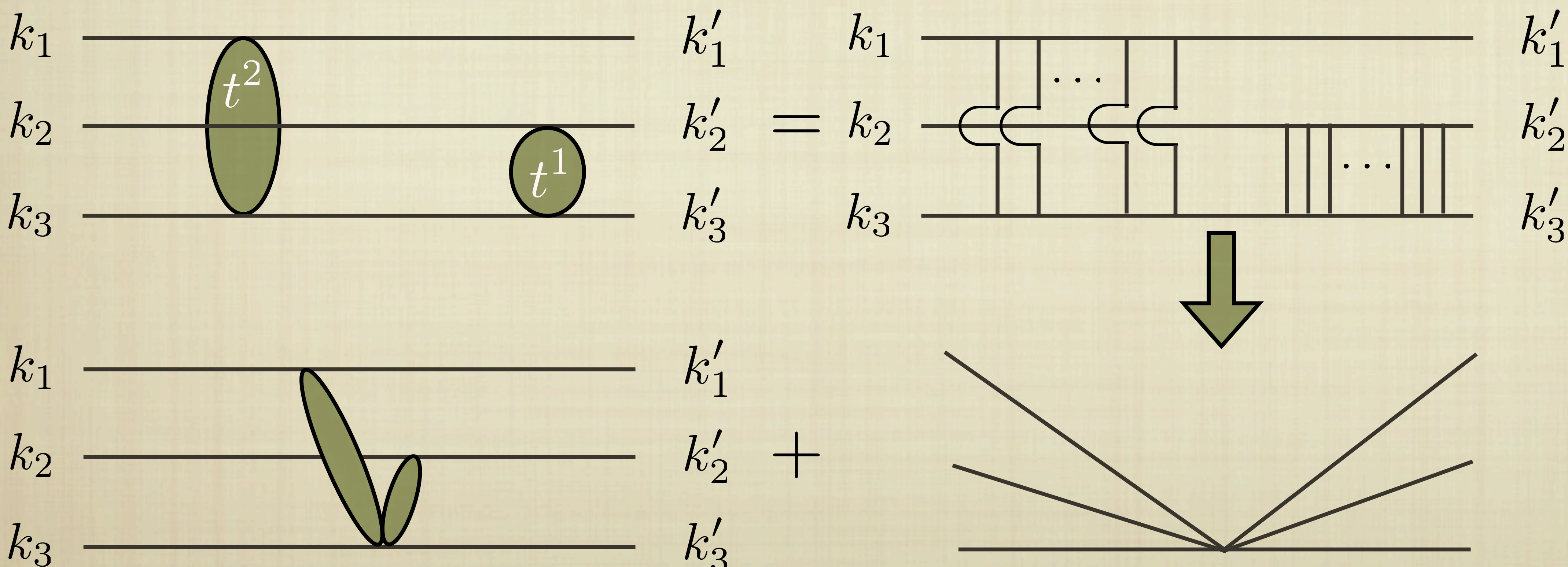


CHIRAL AMPLITUDES

ON-SHELL PART

OFF-SHELL PART



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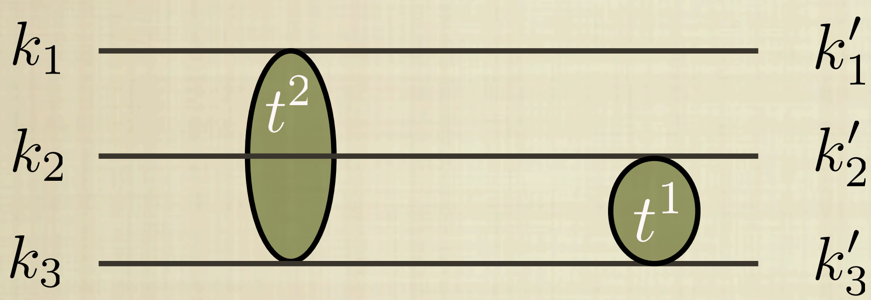
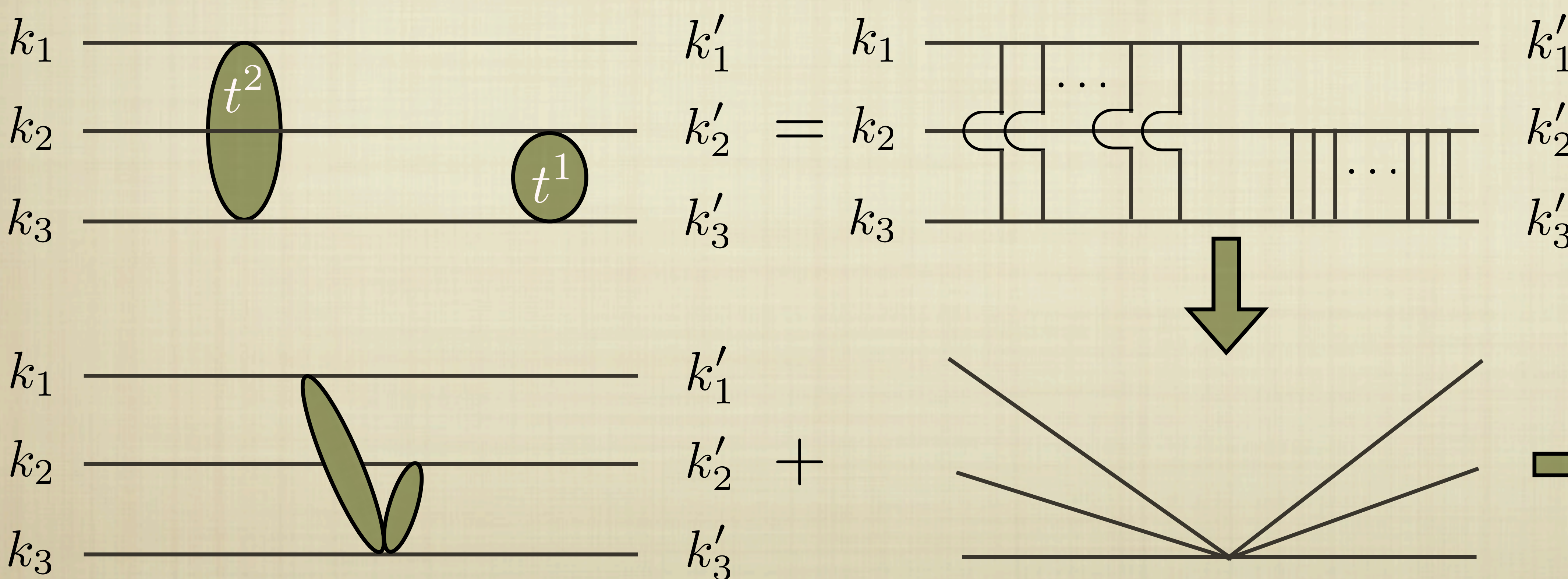
- t^I IS THE TWO BODY t-MATRIX → $t = V + V\tilde{g}t$

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



CHIRAL AMPLITUDES → ON-SHELL PART, OFF-SHELL PART

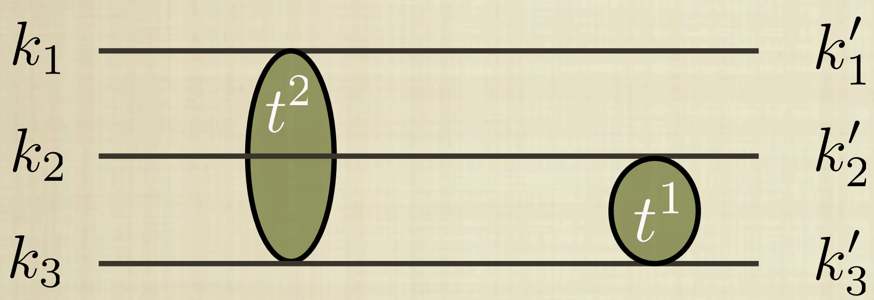


→ CANCELLATION IN THE SU(3) LIMIT

[14] F J. LLANES-ESTRADA, E. OSET AND V. MATEU, PHYS. REV. C 69, 055203 (2004).

- t^I IS THE TWO BODY t-MATRIX ⟹ $t = V + V\tilde{g}t$

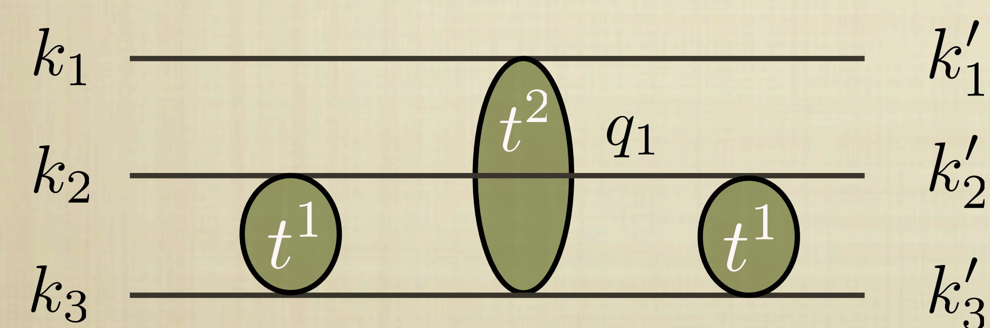
- g^{IJ} IS THE THREE-BODY GREEN



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

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

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



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

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

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

The NπK system

- We take as coupled channels $p\pi^0K^0, n\pi^0K^+, p\pi^-K^+, n\pi^+K^0$.

$\pi N \Rightarrow$

charge 0: $K^+\Sigma^-, K^0\Sigma^0, K^0\Lambda, \pi^-p, \pi^0n, \eta n$

charge +1: $K^+\Sigma^0, K^0\Sigma^+, K^+\Lambda, \pi^0p, \pi^+n, \eta p$

$\pi K \Rightarrow$

charge 0: π^-K^+, π^0K^0

charge +1: π^+K^0, π^0K^+

$KN \Rightarrow$

charge 0: K^0n

charge +1: K^0p, K^+n

charge +2: K^+p

Previous three-body systems studied

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

Previous three-body systems studied

- $\pi\bar{K}N, \pi\pi\Sigma, \pi\pi\Lambda, \pi\eta\Sigma, \pi\eta\Lambda, \pi K\Xi$ → 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			
Σ(1560)	10-100	1590	70
Σ(1620)	10-100	1630	39
Σ(1660)	40-200	1656	30
Σ(1770)	60-100	1790	24
Isospin = 0			
Λ(1600)	50-250	1568, 1700	60, 136
Λ(1810)	50-250	1740	20

Previous three-body systems studied

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

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

Previous three-body systems studied

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

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

	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	

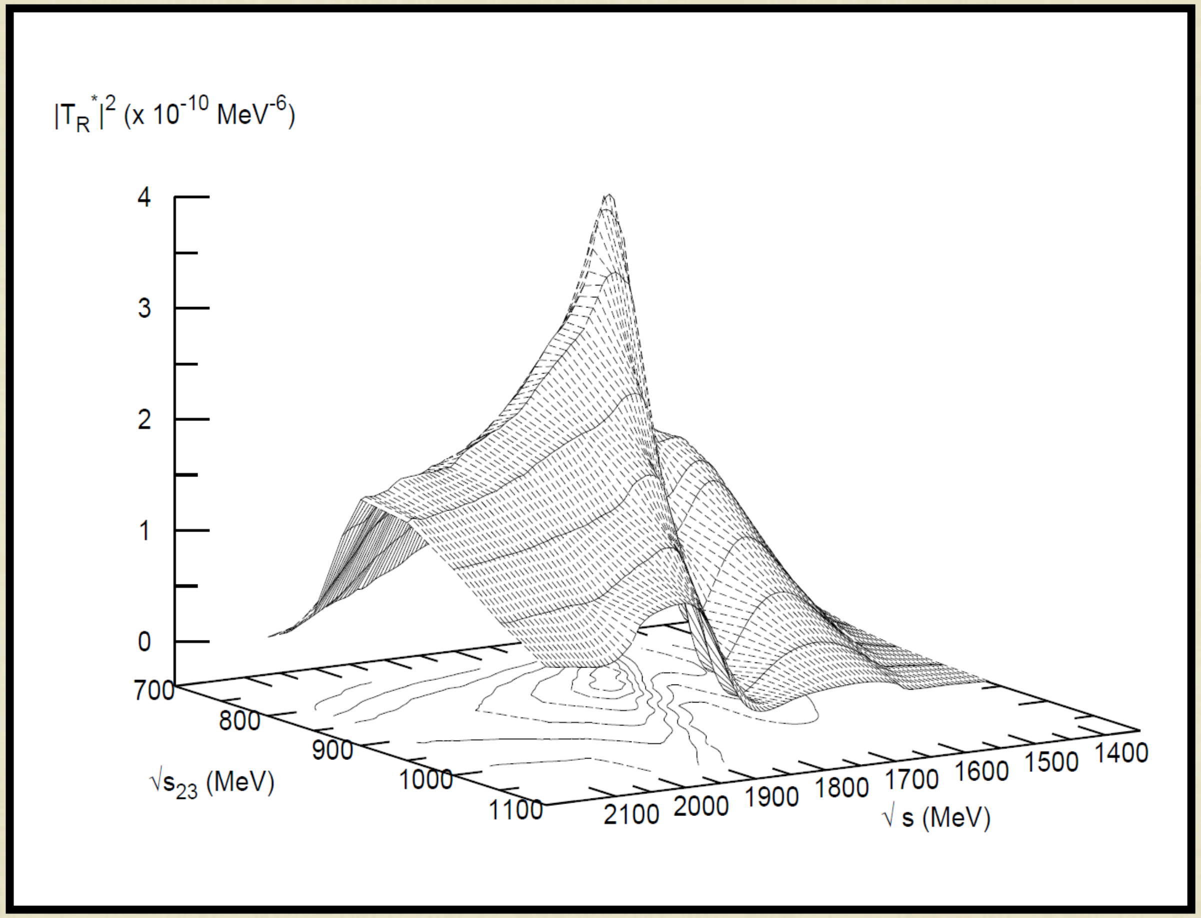
Previous three-body systems studied

- $\pi\bar{K}N, \pi\pi\Sigma, \pi\pi\Lambda, \pi\eta\Sigma, \pi\eta\Lambda, \pi K\Xi$ → 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).
- $\phi K\bar{K}$, $\phi\pi\pi$ → X(2175)

Results NπK System

- We do not find any peak around 1520 MeV.

- Bump around 1720 MeV for total isospin zero with pion-kaon pair in isospin 1/2.



- A bump in this energy region also in the time delay analysis of KN data by N. G. Kelkar et. al. JPG 29, 1001 (2003).

Summary and Future plans

- A broad bump is obtained in the study of the $\pi K N$ system around 1700 MeV.
- 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) .
- 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!!