

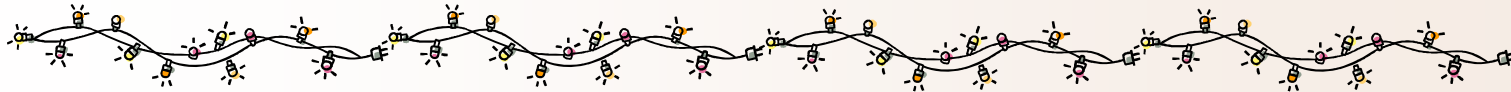
特定領域研究「ストレンジネスで探るクォーク多体系」理論班

『ストレンジネスを含むクォーク多体系分野の理論的将来を考える』

平成21年2月27-28日 KKR熱海@熱海市

ベクトル中間子を含むハドロン共鳴

~ Radiative decays of mesons as dynamically generated resonances ~



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3) Murcia University, Spain, 4) Valencia University, Spain.

A1, B1 RADIATIVE DECAYS WITH HIDDEN GAUGE FORMALISM

• H. Nagahiro, L. Roca, A. Hosaka and E. Oset, Phys. Rev. **D79**, 014015, (2009).

RADIATIVE DECAYS OF MESONS etc.

- H. Nagahiro, L. Roca, E. Oset and B.S. Zou, Phys. Rev. **D78**, 014012 (2008).
- H. Nagahiro, L. Roca and E. Oset, Eur. Phys. J. **A 36**, 73-84 (2008).
- H. Nagahiro, L. Roca, E. Oset, Phys. Rev. **D77**, 034017 (2008).
- H. Nagahiro, J. Yamagata-Sekihara, E. Oset and S. Hirenzaki, e-print arXiv:0809.3717 [hep-ph].
- R. Molina, A. Hosaka, H. Nagahiro, E. Oset, *in preparation*.

background

■ ハドロン-ハドロン系で構成される共鳴状態

- » pseudo-scalar – pseudo-scalar 系 ($\pi\pi$, KK^{bar} , etc.)
 - › σ , $f_0(980)$, $a_0(980)$ scalar mesons
- » pseudo-scalar – baryon (πN , ηN , $K\Sigma$, ... / $\pi\Sigma$, $K^{\text{bar}}N$, ...)
 - › $N^*(1535)$, $\Lambda(1405)$ baryon resonances
- » **ベクトル中間子**を含むハドロン共鳴の研究
 - › pseudo-scalar– vector \rightarrow axial vector meson ($\sim 1\text{GeV}$)
(π , K , η) (ρ , K^* , ω , ϕ) $a_1(1260)$, $b_1(1235)$, $K_1(1270)$ two pole, etc...
- » **ベクトル-ベクトル相互作用のある場合**
 - › vector(ρ) – vector(ρ/D^*) \rightarrow $f_0(1370)$, $f_2(1270)$ / $D^*_2(2460)$, $D^*_1(2640)$, $D^*_0(2600)?$,
 - › vector – baryon \rightarrow N^* , Δ^* , ...
 - Kaneko, Nagahiro, Hosaka; (ρ -N with hidden) (金子, 春の学会@立教 2009.3)
 - M. Lutz etc., VN coupled channel
 - team E. Oset (**ρ - Δ system**)

motivation

- 構造を知る ~ ハドロン分子 ? qq^{bar}/qqq 状態 ?
 - » 生成反応をみる
 - › $K_1(1270)$ two poles evidence in $K^-p \rightarrow K^- \pi^+ \pi^+ p$
L.S.Geng, E.Oset, L.Roca, J.A.Oller, PRD75(07)014017.
 - » 環境を変えて応答をみる
 - › mesic nuclei ... hadrons in matter
 - eta mesic nuclei 《 $N^*(1535)$ in medium》, Kaonic nuclei 《 $L(1405)$ in medium》 ... etc.
 - large width ($\Gamma \sim 100$ MeV) や meson mass $m_{\text{meson}} > 1\text{GeV}$ の時、難あり
 - » **崩壊幅をみる**
 - › strong decay width
 - › **radiative decay width**
- vector meson を含む系 and/or vector meson を通した崩壊
 - » vector 粒子の導入の仕方
 - › Tensor formalism, vector formalism, **hidden gauge formalism**,...

Recent (our) works

■ radiative decays of dynamically generated resonances

» radiative decays of axial vectors (PV)

- › $a_1(1260), b_1(1235), h_1(1170), h_1(1380), f_1(1285), f_1(1420)$, two $K_1(1270)$'s $\rightarrow P\gamma$

L. Roca, A. Hosaka, E. Oset, Phys. Lett. B658 (2007) 17-26.

H. Nagahiro, L. Roca, E. Oset, Phys.Rev.D77 (2008) 034017.

» $f_0(980)/a_0(980) \rightarrow V\gamma$ (KK^{bar} loop contribution)

H. Nagahiro, L. Roca, E. Oset, Eur.Phys.JA36 (2008) 73.

- › proposal at COSY

» ($f_0(1370/1500/1710) \rightarrow V\gamma$)

H. Nagahiro, L. Roca, E. Oset, B.S. Zou, Phys. Rev. D78 (2008) 014012.

- › (KK^{bar} loop contribution (not dynamically generated resonance))

» **$a_1(1260), b_1(1235)$ radiative decays with hidden gauge formalism**

H.Nagahiro, L.Roca, A. Hosaka, E. Oset, Phys.Rev.D79 (2009) 014015.

» ρ - ρ : $f_0(1370)$ and $f_2(1270)$

R. Molina, D. Nicmorus, E. Oset, Phys.Rev.D78 (2008) 114018.

- › their radiative decays into $\gamma\gamma$

H.Nagahiro, J.Sekihara-Yamagata, S.Hirenzaki, E.Oset, hep-ph/0809.3717. ... ?

» ρ - D^* : $D^*_2(2460), D^*_1(2640), D^*_0(2600)$

R. Molina, A. Hosaka, H. Nagahiro, E. Oset, *in preparation*

Introduction : radiative decays of axial vector mesons

- radiative decays of axial vectors $A \rightarrow P\gamma$

» give information **on nature of the axial-vectors**

- some works for radiative decays of axial vectors

- > quark model + vector meson dominance (VMD)

J.L.Rosner, PRD23 (1981) 1127.

$$- \Gamma_{a^+ \rightarrow \pi^+ \gamma} = 1.0 \sim 1.6 \text{ MeV}; \Gamma_{b^+ \rightarrow \pi^+ \gamma} = 184 \pm 30 \text{ keV}$$

- > effective Lagrangian + VMD

L.Roca, J.E.Palomar, E.Oset, PRD70 (2004) 094006.

$$- \Gamma_{a^+ \rightarrow \pi^+ \gamma} = 320 \sim 470 \text{ keV}; \Gamma_{b^+ \rightarrow \pi^+ \gamma} = 19 \sim 36 \text{ keV}$$

- > based on the chiral unitary approach (as a quasi-bound state of VP)

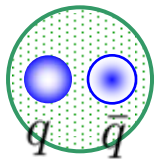
L.Roca, A. Hosaka, E. Oset, PLB658 (2007) 17; [H.Nagahiro](#), L.Roca, E. Oset, PRD77(08)034017.

$$- \Gamma_{a^+ \rightarrow \pi^+ \gamma} = 460 \pm 100 \text{ keV}; \Gamma_{b^+ \rightarrow \pi^+ \gamma} = 210 \pm 40 \text{ keV}$$

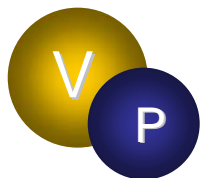
[H.Nagahiro](#), L.Roca, A. Hosaka, E. Oset, PRD79 (2009) 014015.

$$- \Gamma_{a^+ \rightarrow \pi^+ \gamma} = 133 \pm 70 \text{ keV}; \Gamma_{b^+ \rightarrow \pi^+ \gamma} = 209 \pm 90 \text{ keV}$$

qq^{bar} composite particle



an elementary particle
in a Lagrangian



a quasi-bound state

++ 実験値 ++

$$- \Gamma_{a^+ \rightarrow \pi^+ \gamma} = 640 \pm 246 \text{ keV [1]}; \Gamma_{b^+ \rightarrow \pi^+ \gamma} = 230 \pm 60 \text{ keV [2]}$$

[1] M.Zielinski et al., PRL52 (1984) 1195. [2] B.Collick et al., PRL53 (1984) 2734.

ダイナミカルに生成される共鳴としての軸性ベクトル中間子

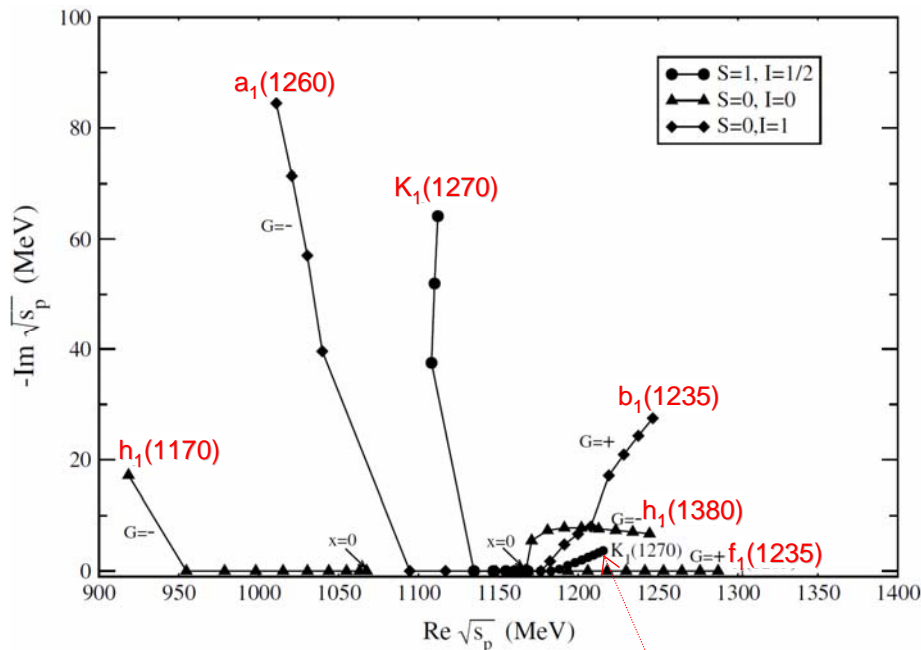
Chiral Unitary approach for low lying axial vectors

L.Roca, E.Oset and J.Singh, PRD72(05)014002

1⁺ resonance ... $b_1(1235)$, $a_1(1260)$, $h_1(1170)$, $h_1(1380)$, $f_1(1285)$, two $K_1(1270)$ s

building blocks

pseudo-scalar octet ... π , K , η
vector nonet ... ρ , K^* , ω , ϕ



assigned axial vectors	pole $\sqrt{s_p}$	main decay channel	
		CUM	PDG
$b_1(1235)$	$1247 - 28 i$	$\omega\pi$	$\omega\pi$
$a_1(1260)$	$1101 - 84 i$	$\rho\pi$	$\rho\pi$
$h_1(1170)$	$919 - 17 i$	$\rho\pi$	$\rho\pi$
$h_1(1380)$	$1245 - 7 i$	KK^*	KK^*
$f_1(1285)$	$1288 - 0 i$...	4π

in unit of MeV

$K_1(1270)$ double pole picture

L.Roca, E.Oset and J.Singh, PRD72(05)014002

$S=1, I=1/2$ channel

	$K_1(1270)_\alpha$		$K_1(1270)_\beta$	
$\sqrt{s_p}$	1112 - i64		1216 - i4	
	g_i	$ g_i $	g_i	$ g_i $
ϕK	1587 - i872	1811	1097 - i400	1168
ωK	-1860 + i649	1970	-1033 + i375	1099
ρK	-1524 + i1154	1912	5274 + i297	5282
$K^* \eta$	27 + i155	157	3459 - i95	3460
$K^* \pi$	4187 - i2098	4683	340 - i984	1041

$K_1(1270)$

$I(J^P)=1/2(1^+)$

$m = 1272 \pm 7 \text{ MeV}$

$\Gamma = 90 \pm 20 \text{ MeV}$

Clear discrepancy between different methods of determination of the $K_1(1270)$ width. (PDG04)

Γ
by experiment
with **Kaon** beam
 $[K^-p \rightarrow K^-2\pi p]$

$>$

Γ
by experiment
with **pion** beam
 $[\pi^-p \rightarrow \Lambda K 2\pi]$

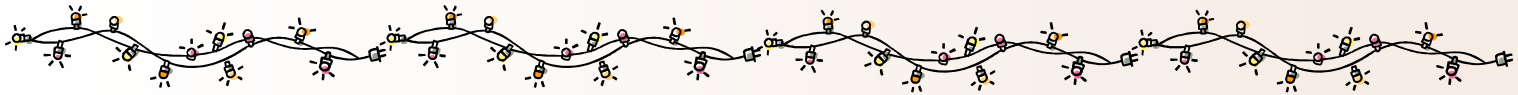
two poles for $K_1(1270)$

experimental supports in $K^-p \rightarrow K^- \pi^+ \pi^0 p$
L.S.Geng, E.Oset, L.Roca, J.A.Oller, PRD75(07)014017.

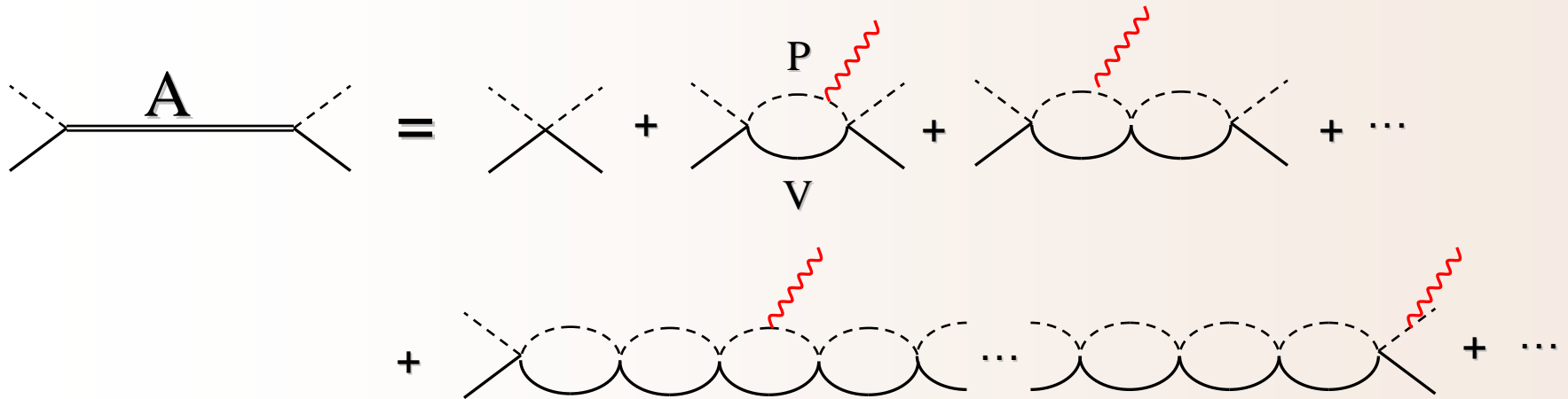
PDG2007

"Well described in the chiral unitary approach of GENG 07 with two poles ..."

Formalism of the radiative decay of the axial vectors as dynamically generated resonances



dynamical generated resonance



==== A ... axial vectors (dynamically generated resonance)

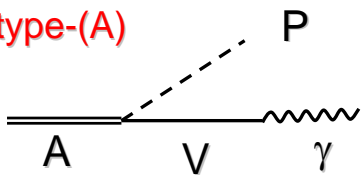
----- P ... pseudoscalar mesons [π , K , η]

———— V ... vector mesons [ρ , ω , K^* , ϕ]

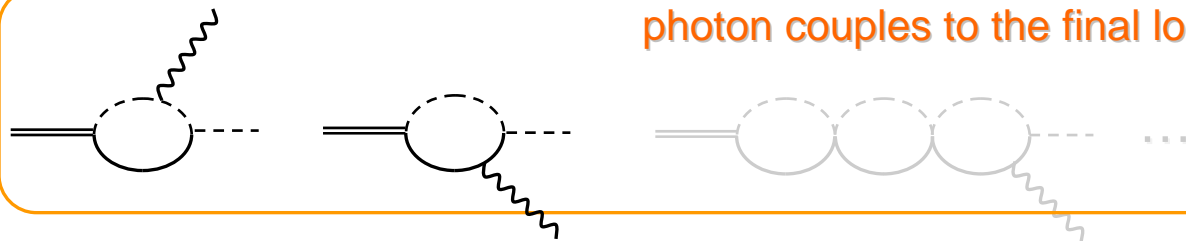
光崩壊計算の定式化

contributing diagrams (taken into account in this work)

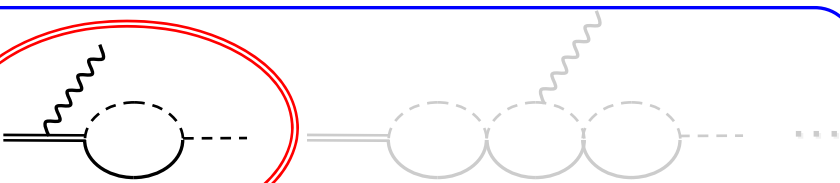
type-(A)



photon couples to the final loop



photon couples to the final vertex



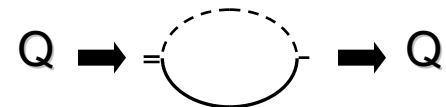
photon couples A or an intermediate loop



to the final P

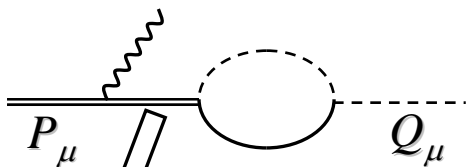
a_1 - π mixing

null contributions from a_1 - π mixing

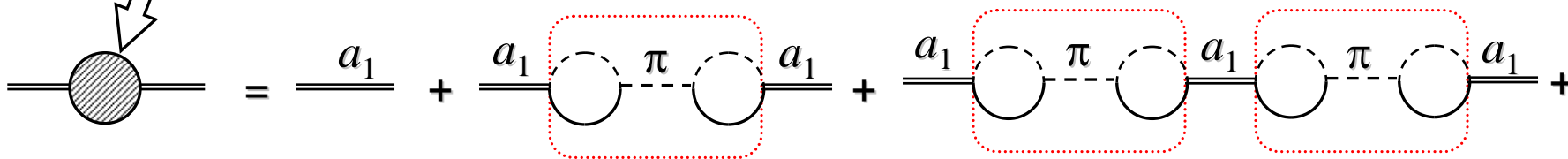


loop function $J(Q^2)$

$$J(Q^2) \sim \int \frac{d^4q}{(4\pi)^4} D(q)D(Q-q)$$



Full propagator of a_1 with a_1 - π mixing



$$\sim \frac{1}{Q^2 - m_A^2} + \frac{1}{Q^2 - m_A^2} J \frac{1}{Q^2 - m_\pi^2} J \frac{1}{Q^2 - m_A^2} + \dots$$

$$= \frac{1}{Q^2 - m_A^2 - \underbrace{J \frac{1}{Q^2 - m_\pi^2} J}_{Q^2 - m_\pi^2}} = \frac{1}{(Q^2 - m_A^2)(Q^2 - m_\pi^2) - J^2}$$

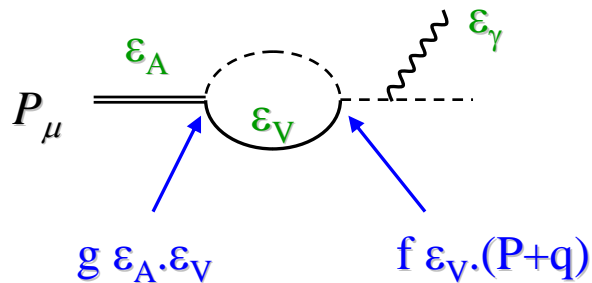
Q ... final pion (pseudo-scalar meson) $Q^2 = m_\pi^2$

if $J(Q^2=m_\pi^2) \neq 0$... \rightarrow propagator $\neq 0$

if $J(Q^2=m_\pi^2) = 0$... \rightarrow amplitude $= 0$

\rightarrow null contribution

null contributions from a_1 - π mixing



$$t_{(5)} \propto \epsilon_A^\mu \int \frac{d^4 q}{(4\pi^4)} \frac{1}{q^2 - m^2} \frac{1}{(P - q)^2 - M^2} \left(-g_{\mu\nu} + \frac{(P - q)_\mu (P - q)_\nu}{M^2} \right) (P + q)^\nu \frac{1}{P^2 - m^2} \epsilon_\gamma \cdot (P - k)$$

$$\equiv \tilde{J}(P^2) P_\mu$$

積分を実行した後は、(どんな関数であれ)

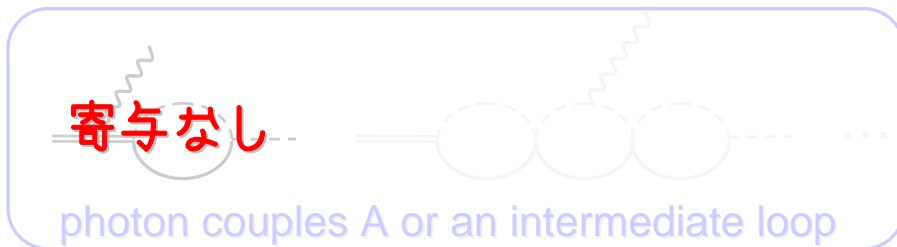
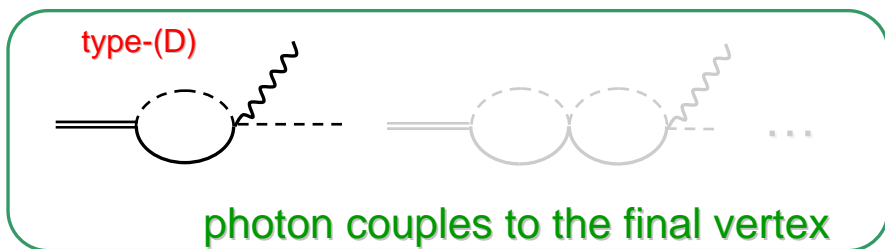
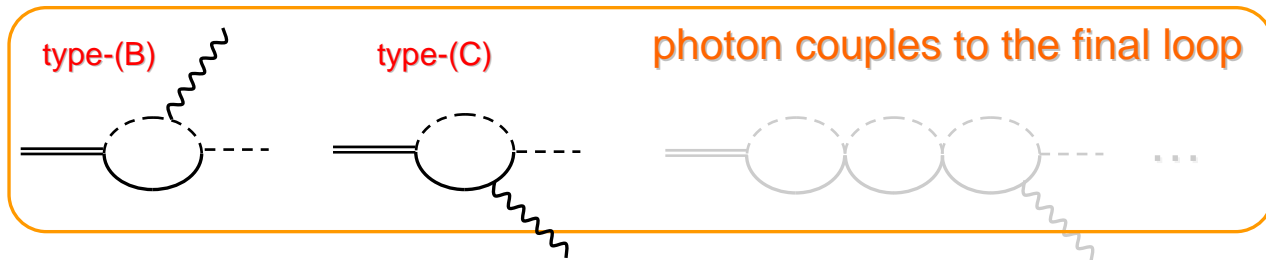
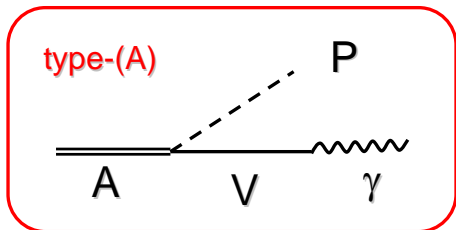
$(P^2$ の関数) $\times P_\mu$

という形になっている。

= 0 by Lorentz condition

光崩壊計算の定式化

contributing diagrams (taken into account in this work)

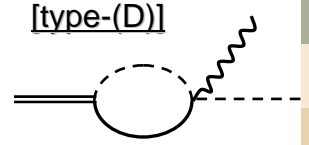


loopを通した a_1 - π mixing \rightarrow 終状態 on shell pion

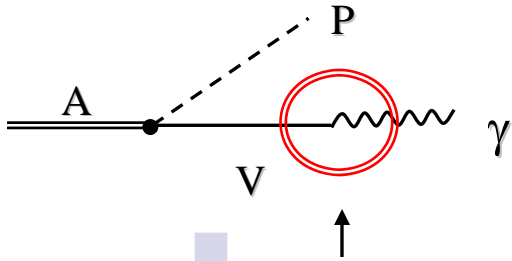
$$t \propto \epsilon_A^\mu \times J(P^2) P_\mu = 0$$

Lorentz condition for on-shell axial

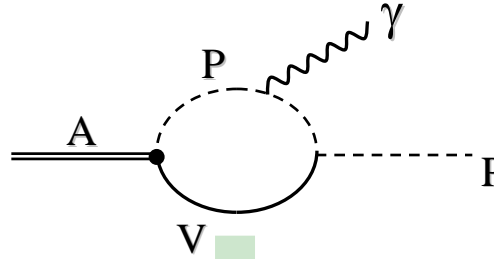
double counting ... ?



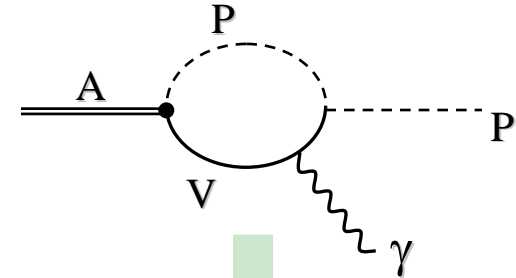
“tree” [type-(A)]



“loop” [type-(B)]

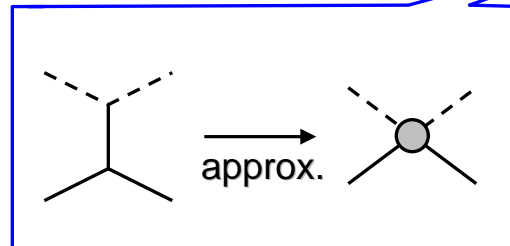
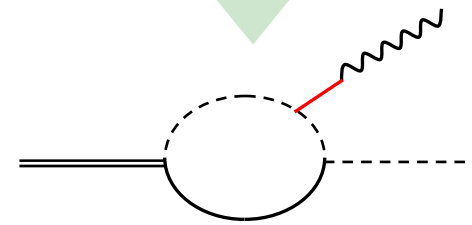
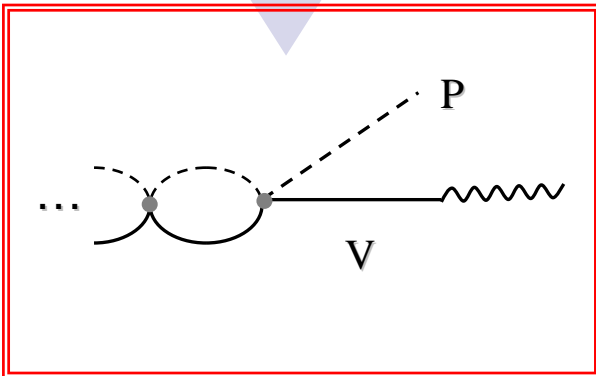


“loop” [type-(C)]

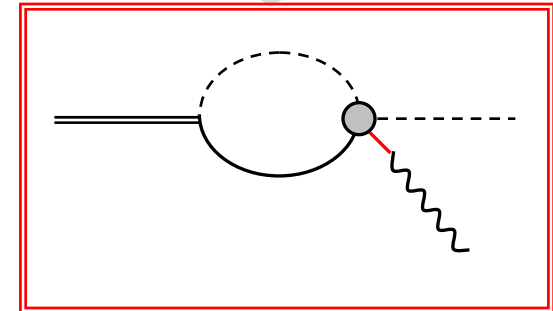


1. we use the vector meson dominance

2. In such a scheme, hidden formalism, photon never couples to a particle line directly. It always couple through a vector meson.

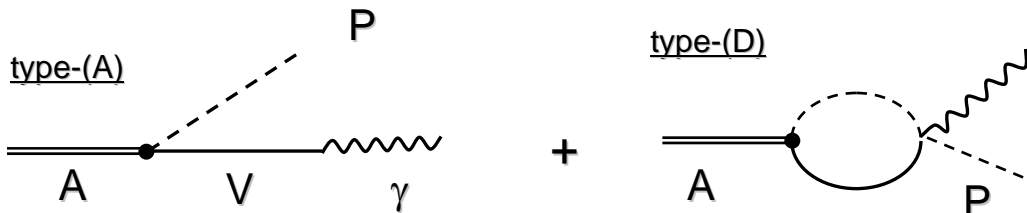


This approx. was already used in $VP \rightarrow VP$ scattering.



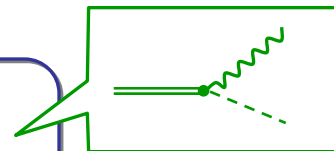
独立な diagram set

①

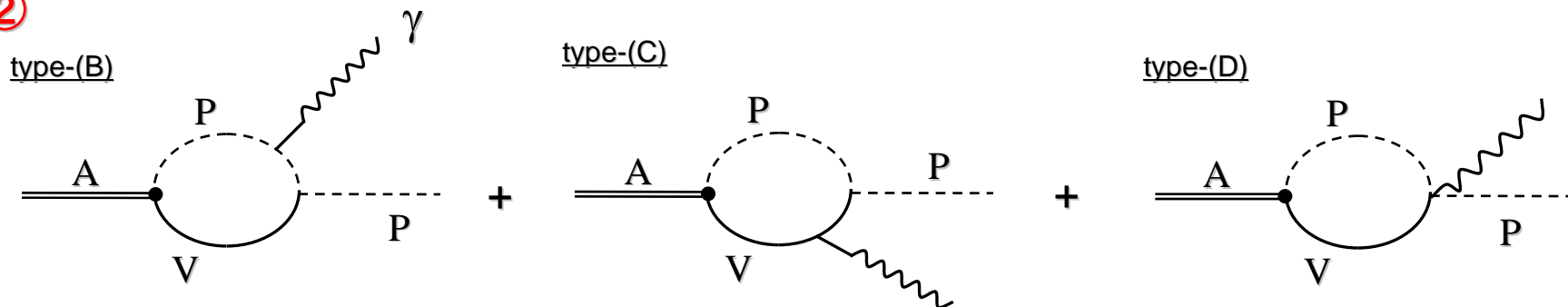


Vector を介して γ と結合するもの

V を介さないもの



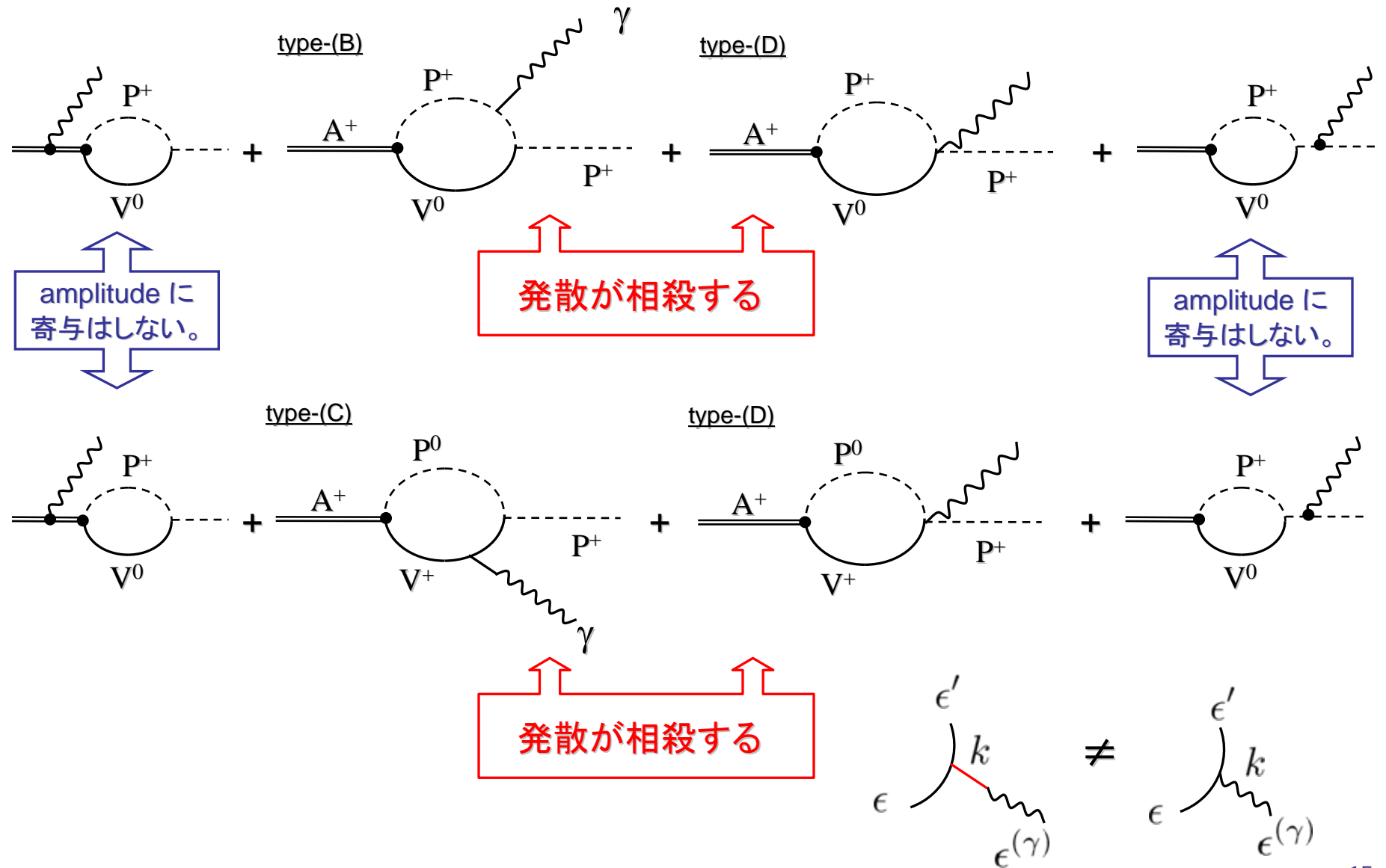
②



どちらを計算すべきか

1. dynamical に生成された共鳴状態という観点からすれば、両者は同一のもの(のはず)。
2. set ① は、explicitに、gauge invariance が見えない。
(このまま計算すると gauge invariant ではない。)
3. type-(D) は発散する。

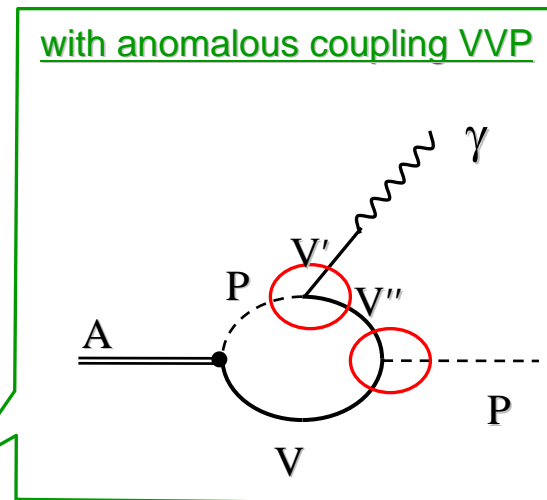
gauge invariant set ② $A^+ \rightarrow \gamma P^+$



数值計算結果

in unit of keV

		$a_1^+(1260) \rightarrow \pi^+\gamma$	$b_1^+(1235) \rightarrow \pi^+\gamma$
type-(B)	K*K	14	26
	$\rho\pi$	119	...
	total	171	26
type-(C)	K*K	30	57
	$\rho\pi$	213	...
	total	373	57
TOTAL		103	159
anomalous		217	4
TOTAL + anomalous		133 ± 70	209 ± 90
experimental value		640 ± 246 [1]	230 ± 60 [2]



- [1] B.Collick et al., PRL53 (1984) 2734.
 [2] M.Zielinski et al., PRL52 (1984) 1195.

quark model
 Rosner, PLD23(1981)1127

1.0 ~ 1.6 MeV

184 ± 30 keV

effective Lagrangian
 Roca et al., PRD70(04)094006

320 ~ 470 keV

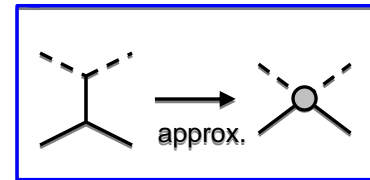
19 ~ 36 keV

discussions : $a_1(1260)$ meson について

- 今のformalismでは実験値の 1/3 ~ 1/4 しか再現できない。
 - » anomalous contribution を入れなければ 1/5 程度。

- 原因は？

(1) もっと高次(?) が必要? $\mathcal{L} = gA_\mu V^\mu P$



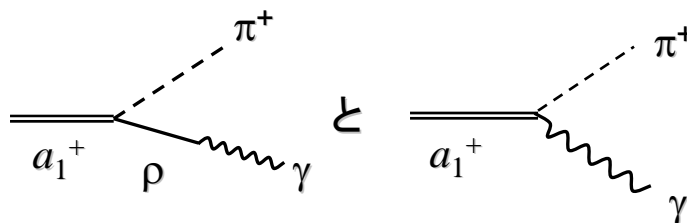
(2) Chiral Unitary approach での記述がよろしくない？

→ 導出されるシリーズの一員である $K_1(1270)$ の two pole picture によって、
 $K\bar{p} \rightarrow K^-\pi^+\pi^+p$ 実験data (ACCMOR Collaboration) は非常によく再現されている。 [PDG, L.S.Geng, E.Oset, L.Roca, J.A.Oller, PRD75(07)014017.]

(3) quark component(?) からの寄与が大きい？

- » ハドロン分子の要素が少ない or core (?) からの光崩壊への寄与が大きい。
 - pole analysis の観点からすれば、 a_1 は殆ど dynamical component
 [T. Hyodo, D. Jido, A. Hosaka, PRC78(08)025203.]

(4) a_1 meson は、extended hidden gauge symmetry Lagrangian に explicit field として導入される。 [M.Bando, T.Kugo, K. Yamawaki, PR164(88)217 他]
 そこでは、lowest で



が、exact に相殺。 ... 何か関係が...??

summary :

- カイラルユニタリモデルを基礎として、axial vector の光崩壊幅の計算を行った。
 - » axial vectors ... dynamical generated resonance
 $b_1(1235)$, $a_1(1260)$, $h_1(1170)$, $h_1(1380)$, $f_1(1285)$, two $K_1(1270)$ s
 - » $A \rightarrow VP$ coupling は、その相対符号も含めてUnitaryモデルから決まる。
- b_1 は良い一致。 a_1 は実験値の 1/3-1/4程度。
 - » 思案中...
- 様々な channel の non-trivial な干渉の効果が重要。
- hidden formalism でベクトル粒子を記述。
 - » "photon が入っている", 及び "dynamical generated object" の場合、注意。
 - » double counting の問題。独立な diagram の選定。
- a_1 に関しては、anomalous VVP coupling からの寄与がより大きい。
 - » 相殺してしまうけど。

Future work

- 実験値に足りない計算結果。
- extended hidden formalism により explicit に導入される a_1 中間子との関係。
- Chiral Unitary Approach で求められる 共鳴と基本粒子との coupling の詳細な形
 - » $f_0(1370) \rightarrow \gamma\gamma$: "tree" diagram \neq gauge inv. [$f_0(1370)$ (ρ - ρ composite)- $\rho\rho$ vertex]
[vector が含まれる場合特に Lorenz の足の構造]