ハドロン、タウ崩壊の レゾナンスカイラルラグランジアン を用いた解析

(work in progress)

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Introduction

- Chiral Perturbation Theory (ChPT)
- Physics in τ Factory (Dalitz plot)
- $\epsilon^{\mu\nu\rho\sigma}$ に比例する相互作用項.

Contents

- Model ($\mathrm{R}\chi\mathrm{PT}$)

- ハドロン分岐比 $V \to P\gamma \quad P \to 2\gamma$
- Form Factor $\eta \to \mu^+\mu^+\gamma$

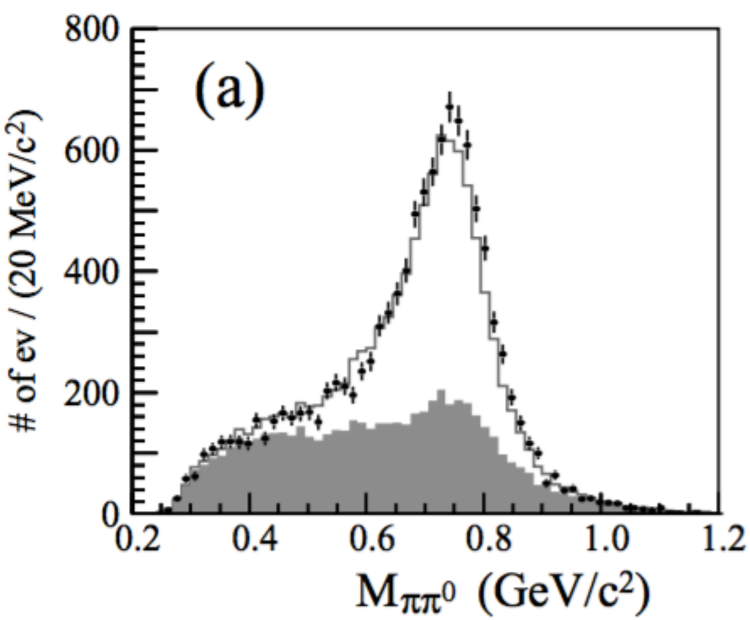
  $\eta' \to \mu^+\mu^-\gamma$
- ~~タウ崩壊 Dalitz Plot~~ $\tau^- \to \nu\eta\pi^-\pi^0$

$V : 1^- \qquad P : 0^-$

Resonance Chiral Perturbation Theory (RχPT)

$$\mathcal{L}_{\mathrm{model}} = \underline{\mathcal{L}_{\mathrm{ChPT}}} + \underline{\mathcal{L}_{\mathrm{Vector}}}$$

有効理論part　　ベクトル中間子が入っている項



Belle, Phys. Lett. B672, 209

$$\tau \to \mathrm{Hadrons}$$

$\rho(770)$ のレゾナンス (?)

Model

Octet
$$\begin{pmatrix} \frac{\pi_3}{2} + \frac{\eta_8}{2\sqrt{3}} & \frac{\pi^+}{\sqrt{2}} & \frac{K^+}{\sqrt{2}} \\ \frac{\pi^-}{\sqrt{2}} & -\frac{\pi_3}{2} + \frac{\eta_8}{2\sqrt{3}} & \frac{K^0}{\sqrt{2}} \\ \frac{K^-}{\sqrt{2}} & \frac{\bar{K}^0}{\sqrt{2}} & -\frac{\eta_8}{\sqrt{3}} \end{pmatrix}$$

Singlet
$$\sim \eta_0 \begin{pmatrix} 1 & & \\ & 1 & \\ & & 1 \end{pmatrix}$$

Model with $SU(3)_L \times SU(3)_R$

$$(\text{Octet}) \quad + \quad (\text{Singlet})$$

	Octet	Singlet
Pseudoscalar	$U = \exp\left(2i\frac{\pi}{f}\right)$	η^0
Vector	V^μ	ϕ_0^μ

Ecker, Gasser, Pich, Rafael

$$\mathcal{L}_\chi = \frac{f^2}{4}\mathrm{Tr}(D_{L\mu}UD_L^\mu U^\dagger) + B\mathrm{Tr}[M(U+U^\dagger)] + \frac{1}{2}\partial_\mu\eta_0\partial^\mu\eta_0 - \frac{1}{2}M_{00}^2\eta_0^2$$
$$+\frac{1}{2}M_{0V}^2\phi_\mu^0\phi^{0\mu} - \frac{Z_{0V}}{4}F_{\mu\nu}^0F^{0\mu\nu} + g_{1V}\phi_\mu^0\mathrm{Tr}\left\{\left(V^\mu - \frac{\alpha^\mu}{g}\right)\left(\frac{\xi M\xi + \xi^\dagger M\xi^\dagger}{2}\right)\right\}$$
$$-ig_{2p}\eta_0\mathrm{Tr}[M(U-U^\dagger)] + M_V^2\mathrm{Tr}\left(V_\mu - \frac{\alpha_\mu}{g}\right)^2 + C\mathrm{tr}QUQU^\dagger,$$

擬スカラー　質量

(Mass in MeV)	π^0	η	η'
PDG	134.9766(6)	547.862(17)	957.78(6)
Result	134.977	547.862	957.78

Preliminary

質量行列 対角化

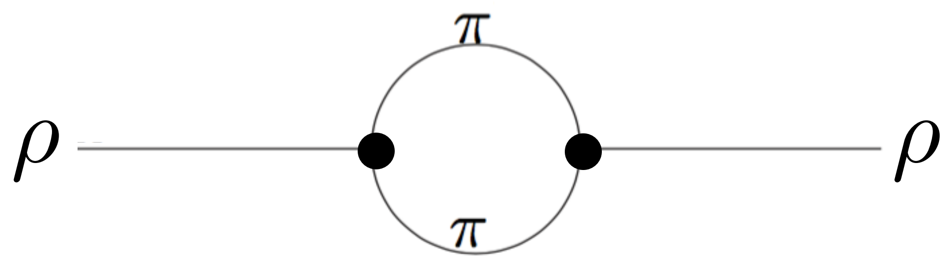
$$M^2 = \begin{pmatrix} M^2_{\pi^+} - \Delta & \dfrac{M^2_{K^+} - M^2_{K^0} - \Delta}{\sqrt{3}} & -\hat{g}_{2p}(M^2_{K^+} - M^2_{K^0} - \Delta) \\ * & M^2_{88} & M^2_{80} \\ * & * & M^2_{00} \end{pmatrix}$$

$\eta_8 - \eta^0$ mixing angle : -17.6°

(1-loop self energy と 電磁補正.)

$\rho\pi\pi$ Coupling の決め方.

-> vector のself-energyを計算する.



$$\begin{cases} \Gamma_{\rho^+ \to \pi^+ \pi^0} \\ \Gamma_{K^{*+} \to (K\pi)^+} \\ \Gamma_{K^{*0} \to (K\pi)^0} \end{cases}$$

上の3つをフィットする.

Preliminary

$$g_{\rho\pi\pi} = 5.88 \pm 0.02$$

$$1 - \frac{M_V^2}{2g^2 f^2} = 0.036$$

$$\left(1 - \frac{M_V^2}{2g^2 f^2} = 0 \ \text{ in VMD}\right)$$

Intrinsic Parity Violation

$$\mathcal{L}_1 = i\epsilon^{\mu\nu\rho\sigma}\mathrm{Tr}[\alpha_{L\mu}\alpha_{L\nu}\alpha_{L\rho}\alpha_{R\sigma} - (R \leftrightarrow L)],$$
$$\mathcal{L}_2 = i\epsilon^{\mu\nu\rho\sigma}\mathrm{Tr}[\alpha_{L\mu}\alpha_{R\nu}\alpha_{L\rho}\alpha_{R\sigma}],$$
$$\mathcal{L}_3 = \epsilon^{\mu\nu\rho\sigma}\mathrm{Tr}[gF_{V\mu\nu}\{\alpha_{L\rho}\alpha_{R\sigma} - (R \leftrightarrow L)\}],$$
$$\mathcal{L}_4 = \frac{1}{2}\epsilon^{\mu\nu\rho\sigma}\mathrm{Tr}[(\hat{F}_{L\mu\nu} + \hat{F}_{R\mu\nu})\{\alpha_{L\rho}, \alpha_{R\sigma}\}]$$

$\epsilon^{\mu\nu\rho\sigma}$ が入った相互作用項.

Fujiwara et. al.
Prog.Theor.Phys.

$$\mathcal{L}_5 = \epsilon^{\mu\nu\rho\sigma}F^0_{V\mu\nu}\mathrm{Tr}[\alpha_{L\rho}\alpha_{R\sigma} - (R \leftrightarrow L)]$$
$$\mathcal{L}_6 = \frac{\eta_0}{f}\epsilon^{\mu\nu\rho\sigma}\mathrm{Tr}F_{V\mu\nu}F_{V\rho\sigma}$$
$$\mathcal{L}_7 = \frac{\eta_0}{f}\epsilon^{\mu\nu\rho\sigma}F^0_{V\mu\nu}F^0_{V\rho\sigma}$$
$$\mathcal{L}_8 = \epsilon^{\mu\nu\rho\sigma}\mathrm{Tr}(\hat{F}_{L\mu\nu} + \hat{F}_{R\mu\nu})\phi^0_\rho\frac{\alpha_{L\sigma} - \alpha_{R\sigma}}{2}$$
$$\mathcal{L}_9 = \frac{\eta_0}{f}\epsilon^{\mu\nu\rho\sigma}\mathrm{Tr}(\hat{F}_{L\mu\nu} + \hat{F}_{R\mu\nu})F_{V\rho\sigma}$$
$$\mathcal{L}_{10} = \frac{\eta_0}{f}\epsilon^{\mu\nu\rho\sigma}\mathrm{Tr}(\hat{F}_{L\mu\nu} + \hat{F}_{R\mu\nu})(\hat{F}_{L\rho\sigma} + \hat{F}_{R\rho\sigma})$$

$\mathrm{SU}(3)$ singlet

η_0 ϕ^0

が入った項.

$$\mathcal{L}_{\mathrm{model}} \sim \sum_{i=1}^{10} c_i\mathcal{L}_i$$

Contents

- ハドロン分岐比 $V \to P\gamma \quad P \to 2\gamma$

Preliminary

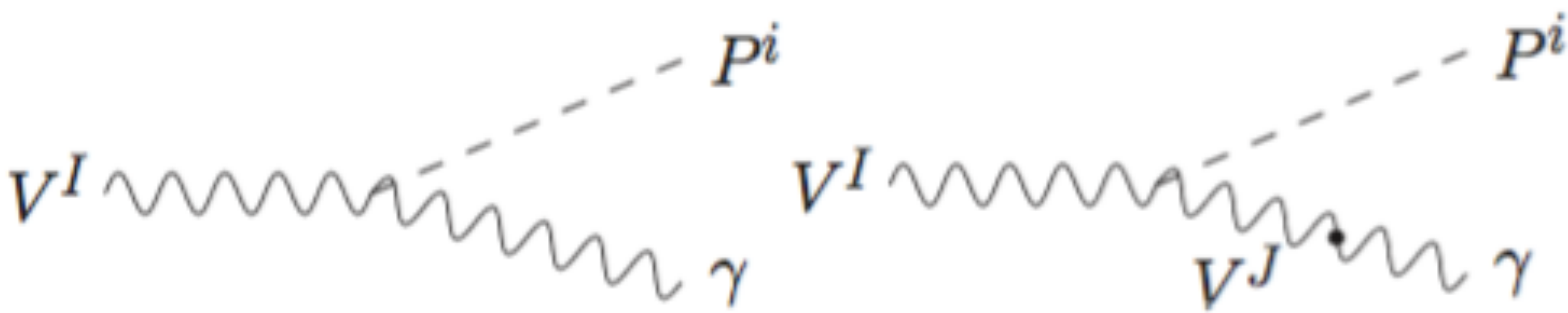
$V : 1^{-} \qquad P : 0^{-}$

Vector Radiative decay $V \to P\gamma$

(Charged modes)

(Γ in MeV)	$\rho^+ \to \pi^+\gamma$	$K^{*+} \to K^+\gamma$
PDG	$(6.7 \pm 0.7) \times 10^{-2}$	$(5.0 \pm 0.5) \times 10^{-2}$
Result	$(7.8 \pm 0.6) \times 10^{-2}$	$(4.2 \pm 0.3) \times 10^{-2}$

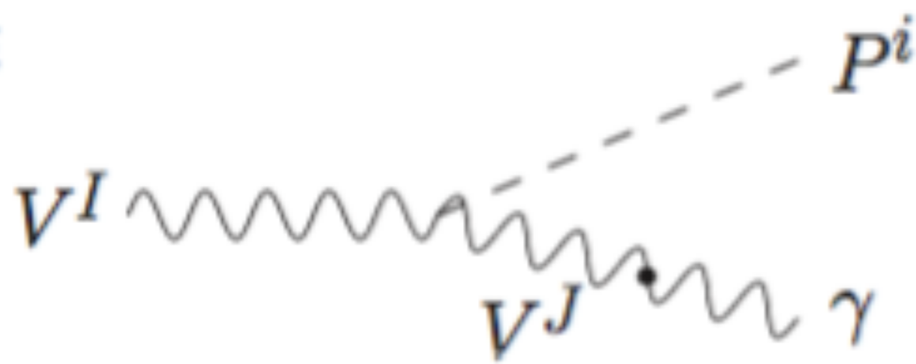
$$|g(c_3 + c_4)| = 0.106 \pm 0.004$$



Vector Radiative decay $V \to P\gamma$

(Neutral modes)

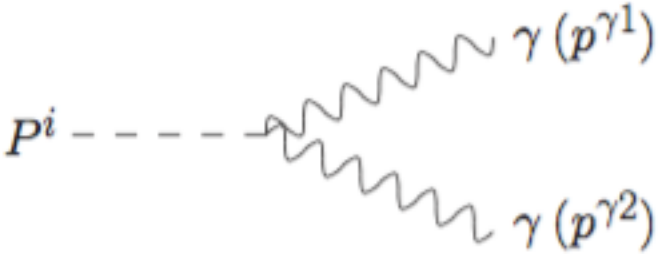
(MeV scale)	$\Gamma[\rho^0 \to \pi^0\gamma]$	$\Gamma[\omega \to \pi^0\gamma]$	$\Gamma[\phi \to \pi^0\gamma]$	$\Gamma[\rho \to \eta\gamma]$
Model	$(4.9 \pm 0.4) \times 10^{-2}$	0.51 ± 0.04	$(5.8 \pm 2.5) \times 10^{-3}$	$(4.8 \pm 0.4) \times 10^{-2}$
PDG	$(8.9 \pm 1.2) \times 10^{-2}$	0.70 ± 0.03	$(5.4 \pm 0.3) \times 10^{-3}$	$(4.4 \pm 0.3) \times 10^{-2}$
(MeV scale)	$\Gamma[\omega \to \eta\gamma]$	$\Gamma[\phi \to \eta\gamma]$	$\Gamma[\phi \to \eta'\gamma]$	$\Gamma[\eta' \to \omega\gamma]$
Model	$(2.6 \pm 0.4) \times 10^{-3}$	$(8.0 \pm 0.7) \times 10^{-2}$	$(3.5 \pm 0.4) \times 10^{-4}$	$(7.2 \pm 1.0) \times 10^{-3}$
PDG	$(3.9 \pm 0.4) \times 10^{-3}$	$(5.5 \pm 0.1) \times 10^{-2}$	$(2.67 \pm 0.09) \times 10^{-4}$	$(5.4 \pm 0.5) \times 10^{-3}$

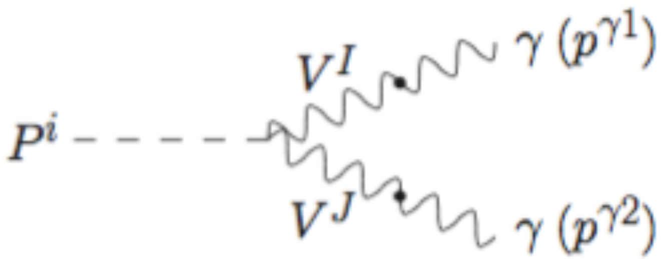


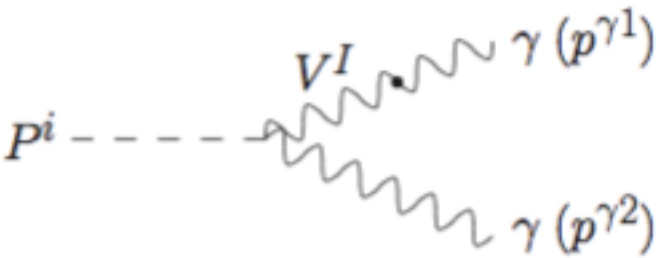
擬スカラー decay

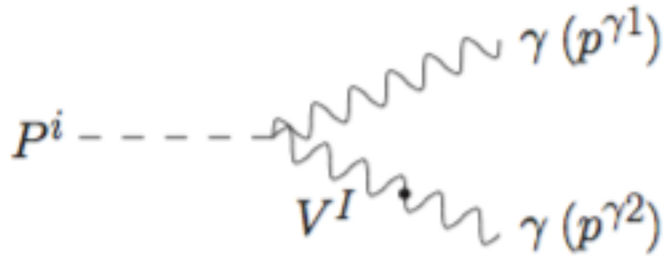
(Γ in MeV)	$\pi^0 \to 2\gamma$	$\eta \to 2\gamma$	$\eta' \to 2\gamma$
PDG	$(7.6 \pm 0.2) \times 10^{-6}$	$(5.2 \pm 0.2) \times 10^{-4}$	$(4.4 \pm 0.2) \times 10^{-3}$
Model	$(7.635 \pm 0.004) \times 10^{-6}$	$(5.2 \pm 0.1) \times 10^{-4}$	$(4.36 \pm 0.03) \times 10^{-3}$

$$\frac{c_6}{g^2} + c_9 + 4c_{10} = (7.1 \pm 0.2) \times 10^{-3}$$









Contents

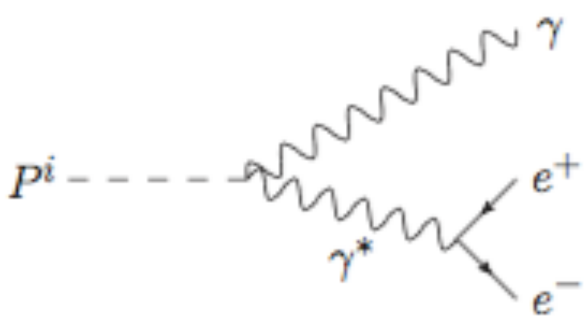
- Form Factor $\eta \to \mu^+ \mu^+ \gamma$

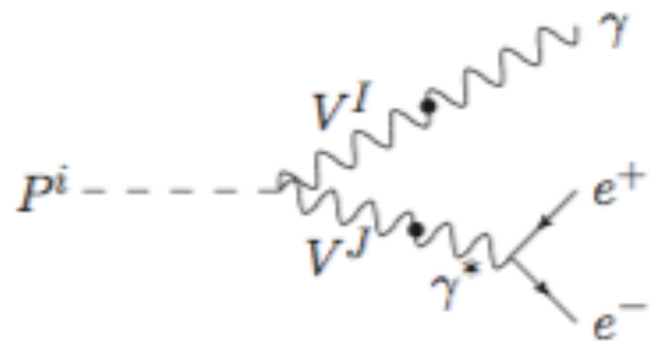
Preliminary

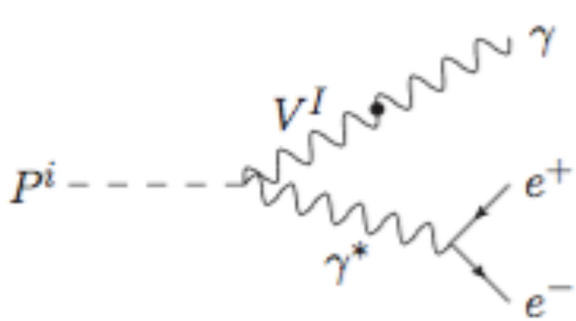
$$\eta \to (\gamma^*)\gamma \to \mu^+\mu^-\gamma$$

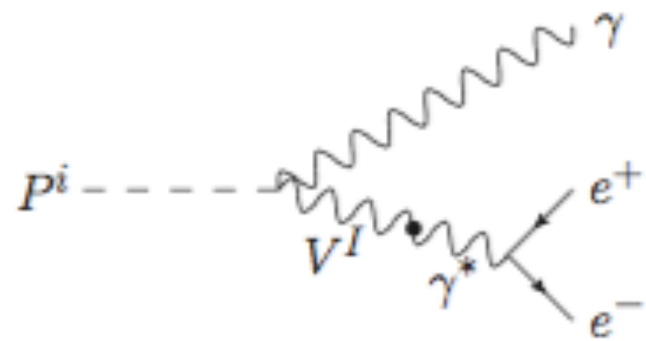
Form Factor

$$\frac{\mathrm{d}\Gamma(\eta \to \mu^+\mu^-\gamma)}{\mathrm{d}s_{+-}} = \frac{2\alpha}{3\pi}\frac{\Gamma(\eta \to 2\gamma)}{s_{+-}}\left(1 - \frac{s_{+-}}{m_\eta^2}\right)^3\left(1 + \frac{2m_\mu^2}{s_{+-}}\right)\left(1 - \frac{4m_\mu^2}{s_{+-}}\right)^{\frac{1}{2}}|F_\eta(s_{+-})|^2$$







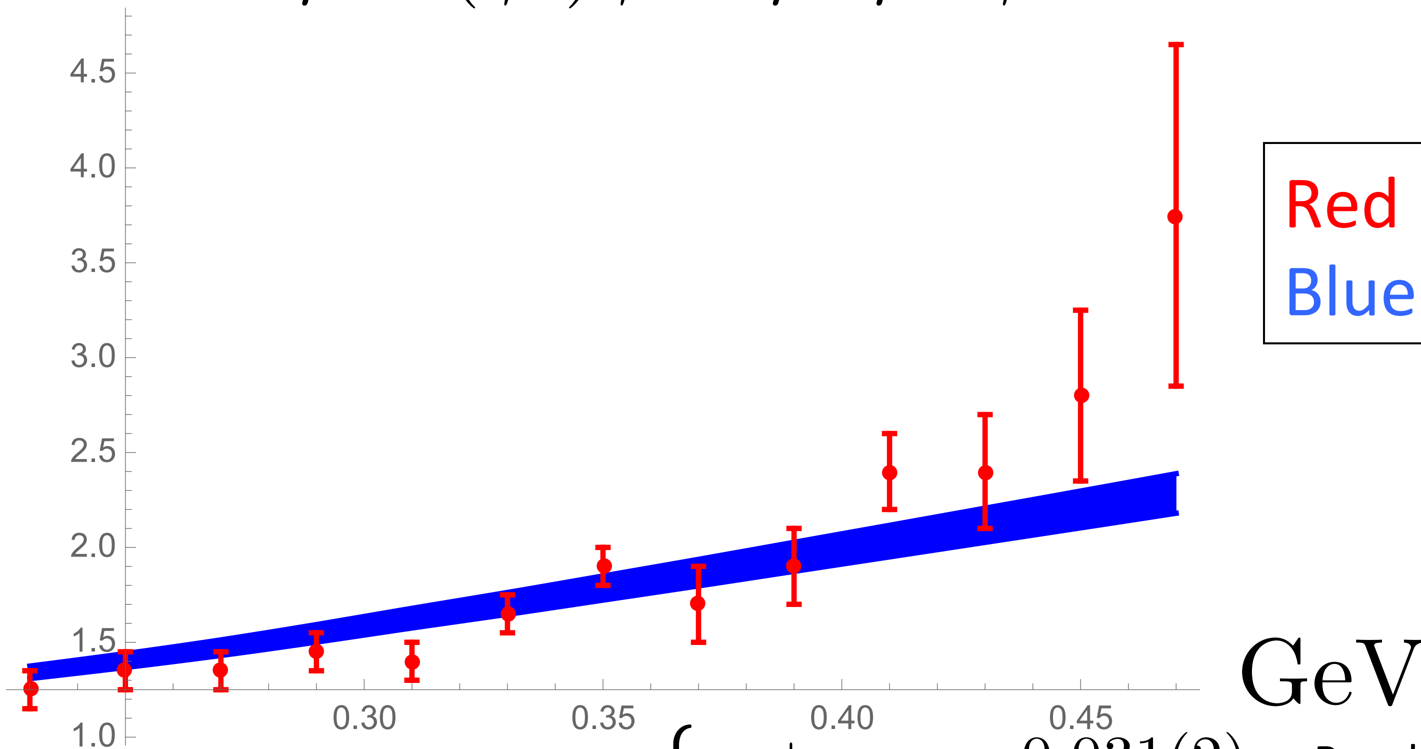


Form Factor Slope

$|F_\eta|^2$

$$\eta \to (\gamma^*)\gamma \to \mu^+\mu^-\gamma$$

Phys. Let. B677



Red : NA60
Blue: Result

$$\begin{cases} c_3 + c_4 = -0.031(2) \\ c_3 + c_4 = -0.038 \end{cases}$$

Result

used in PRD54, 5611

$$g = 3.4 \pm 0.2$$

$$\frac{d\Gamma(\eta \to \mu^+\mu^-\gamma)}{ds_{+-}} = \frac{2\alpha}{3\pi}\frac{\Gamma(\eta \to 2\gamma)}{s_{+-}}\left(1 - \frac{s_{+-}}{m_\eta^2}\right)^3\left(1 + \frac{2m_\mu^2}{s_{+-}}\right)\left(1 - \frac{4m_\mu^2}{s_{+-}}\right)^{\frac{1}{2}}|F_\eta(s_{+-})|^2$$

結論

- RχPT で, IP を破るハドロン崩壊を解析した.
- (octet) + (singlet) のmodel で、質量行列の固有値をフィットし、mixing angle を決めた.
- SU(3) singlet が入った項($\mathcal{L}_5, \cdots, \mathcal{L}_{10}$) を含んだIPの破れの効果を取り入れた.

結論

- Radiative decay ($\rho^+ \to \pi^+\gamma$ 等.)について、分岐比の桁は上手く説明できていた. IPVの項についても、SU(3) breaking を入れると更に改善される (と期待される.)

- $\eta \to \mu^+\mu^-\gamma$ のForm Factor は実験値と合っていた.

今後の展望.

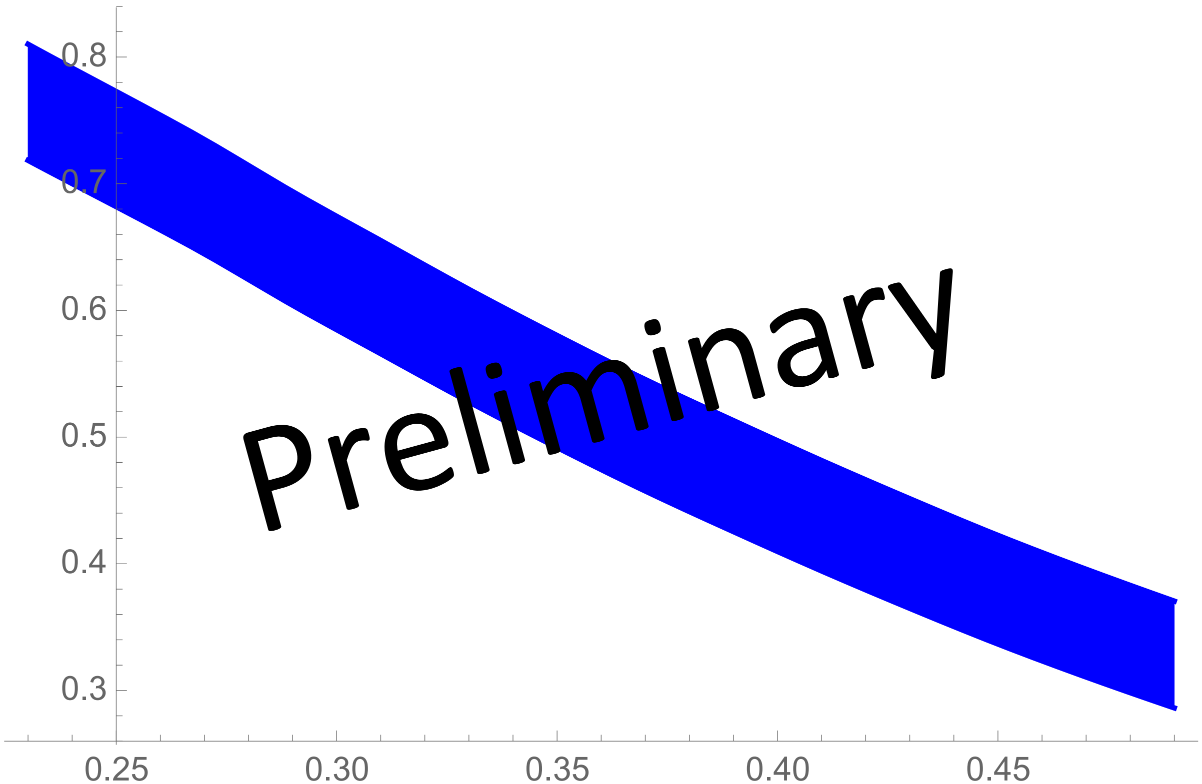
- τ decay の Dalitz plot は計算中 (coming soon)
- Dalitz分布を計算中 for

$\pi^0 \to e^+e^-\gamma,\ \eta \to e^+e^-\gamma,\ \eta' \to e^+e^-\gamma,\ \omega \to \pi^0\mu^+\mu^-, \phi \to \pi^0\mu^+\mu^-,$

Back Up

	$\Gamma[\rho \to \pi\pi]$	$\Gamma[K^{*\pm} \to (K\pi)^{\pm}]$	$\Gamma[K^{*0} \to (K\pi)^{0}]$
Result	152.0	42.5	42.2
PDG	149.1 ± 0.8	46.2 ± 1.3	47.4 ± 0.6

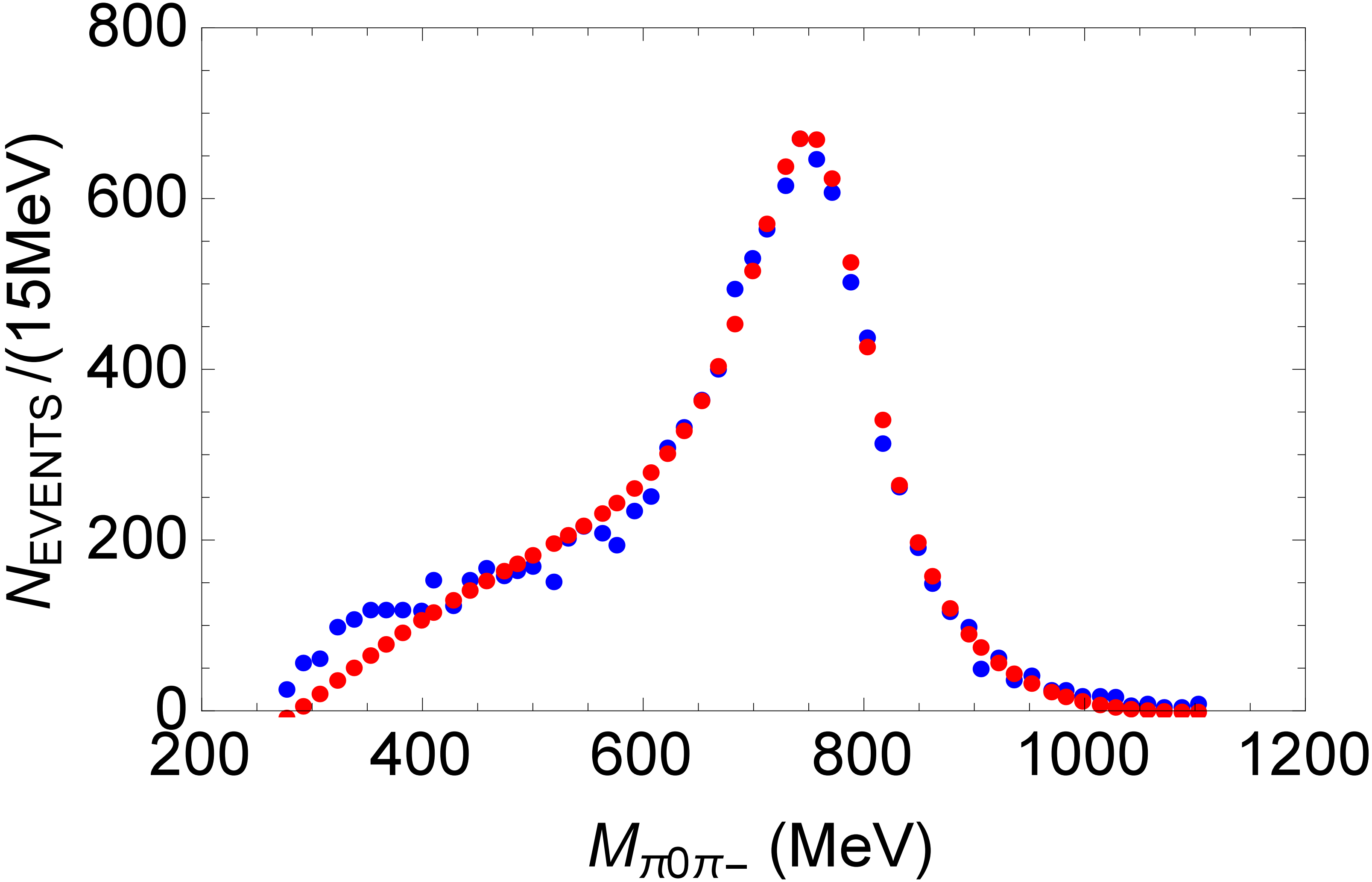
$$\eta' \to \gamma^* \gamma \to \mu^+ \mu^- \gamma$$



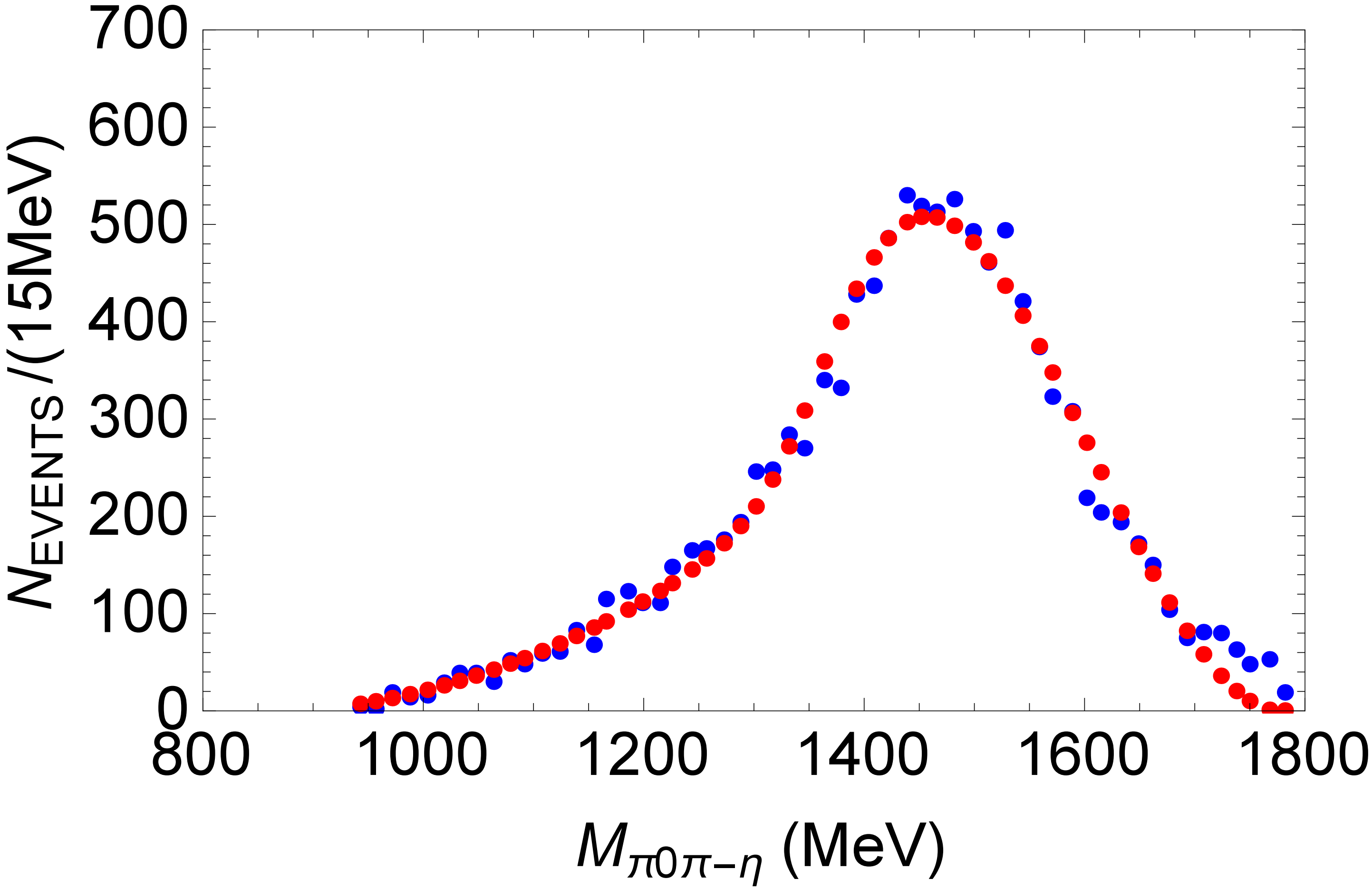
他にも、 $\pi^0 \to e^+ e^- \gamma,\ \eta \to e^+ e^- \gamma,\ \eta' \to e^+ e^- \gamma,$

$\omega \to \pi^0 \mu^+ \mu^-, \phi \to \pi^0 \mu^+ \mu^-,$ などを計算中です.

Tau



800
600
400
200
0
200
400
600
800
1000
1200
$N_{EVENTS}/(15MeV)$
$M_{\pi 0 \pi -}$ (MeV)


700
600
500
400
300
200
100
0
N_{EVENTS}/(15MeV)
800
1000
1200
1400
1600
1800
$M_{\pi0\pi-\eta}$ (MeV)