Study of anomalous tau lepton decay using chiral Lagrangian with vector mesons

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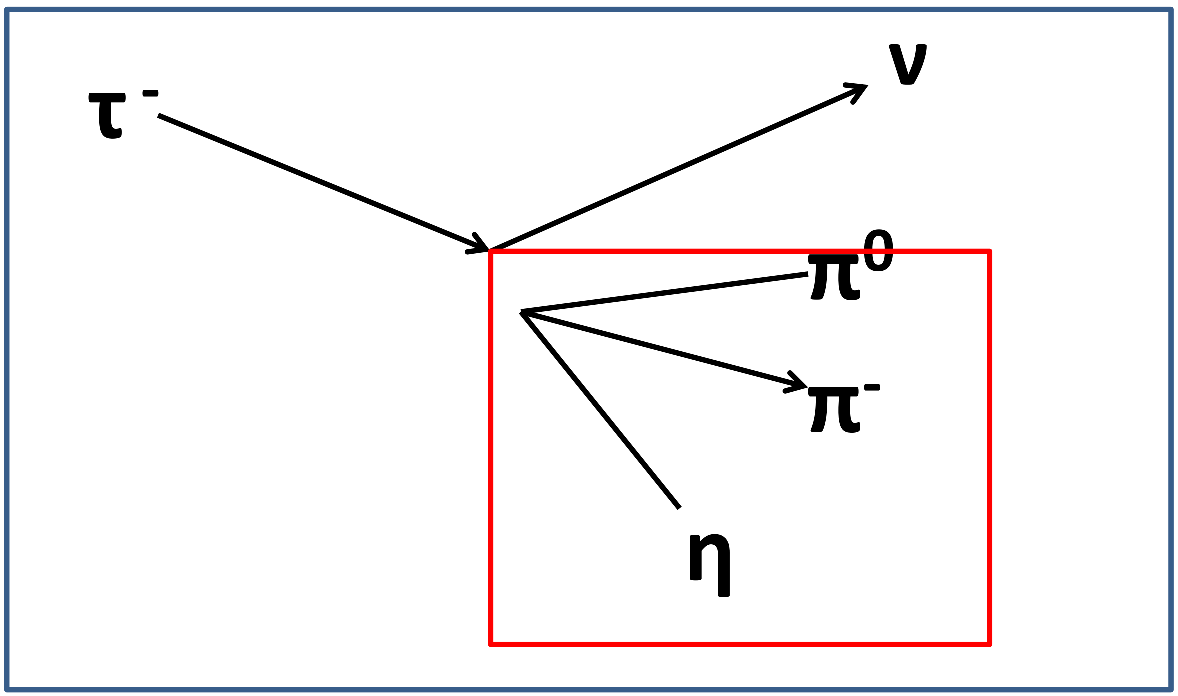
Anomalous tau decay

- τ hadronic decays

which involves Intrinsic parity violation

$\tau^- \rightarrow \eta \; \pi^- \; \pi^0 \; \nu$ through vector current



Intrinsic Parity violation(IPV) versus **G parity** (Isospin) violation

- $< \eta \quad \pi^- \quad \pi^0 \,|\bar{d}\gamma_\mu \mathrm{u}|0>$ $\quad < \eta \quad \pi^- \quad \pi^0 \,|\bar{d}\gamma_\mu\gamma_5 \mathrm{u}|0>$

Intrinsic Parity **V(+1)→ $\eta\pi^-\pi^0$ (-1)**

G parity **A(-1)→ $\eta\pi^-\pi^0$ (+1)**

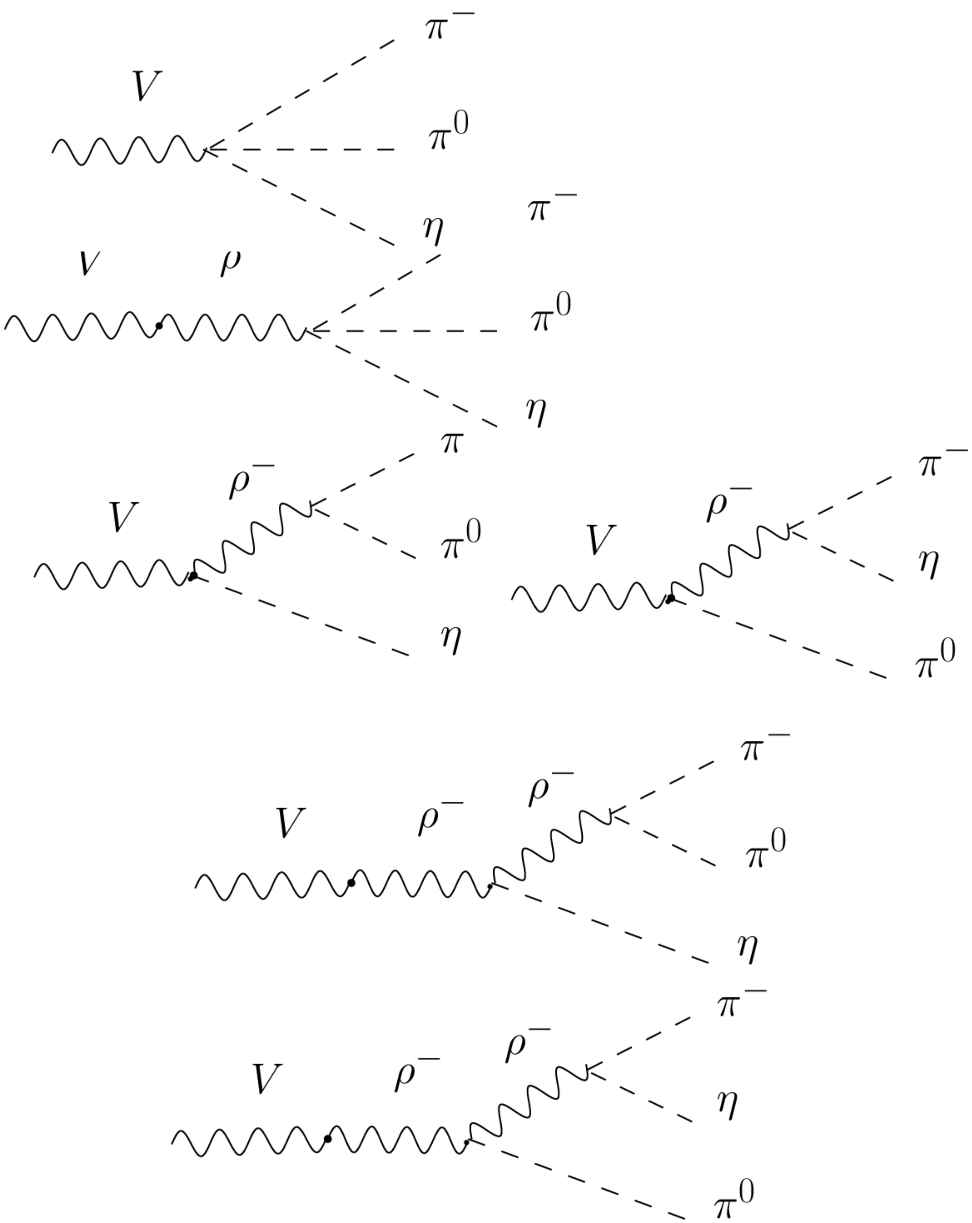
Axial vector contribution is suppressed by (approximate) G parity conservation

We aim to compute both Vector and Axial vector form factors.

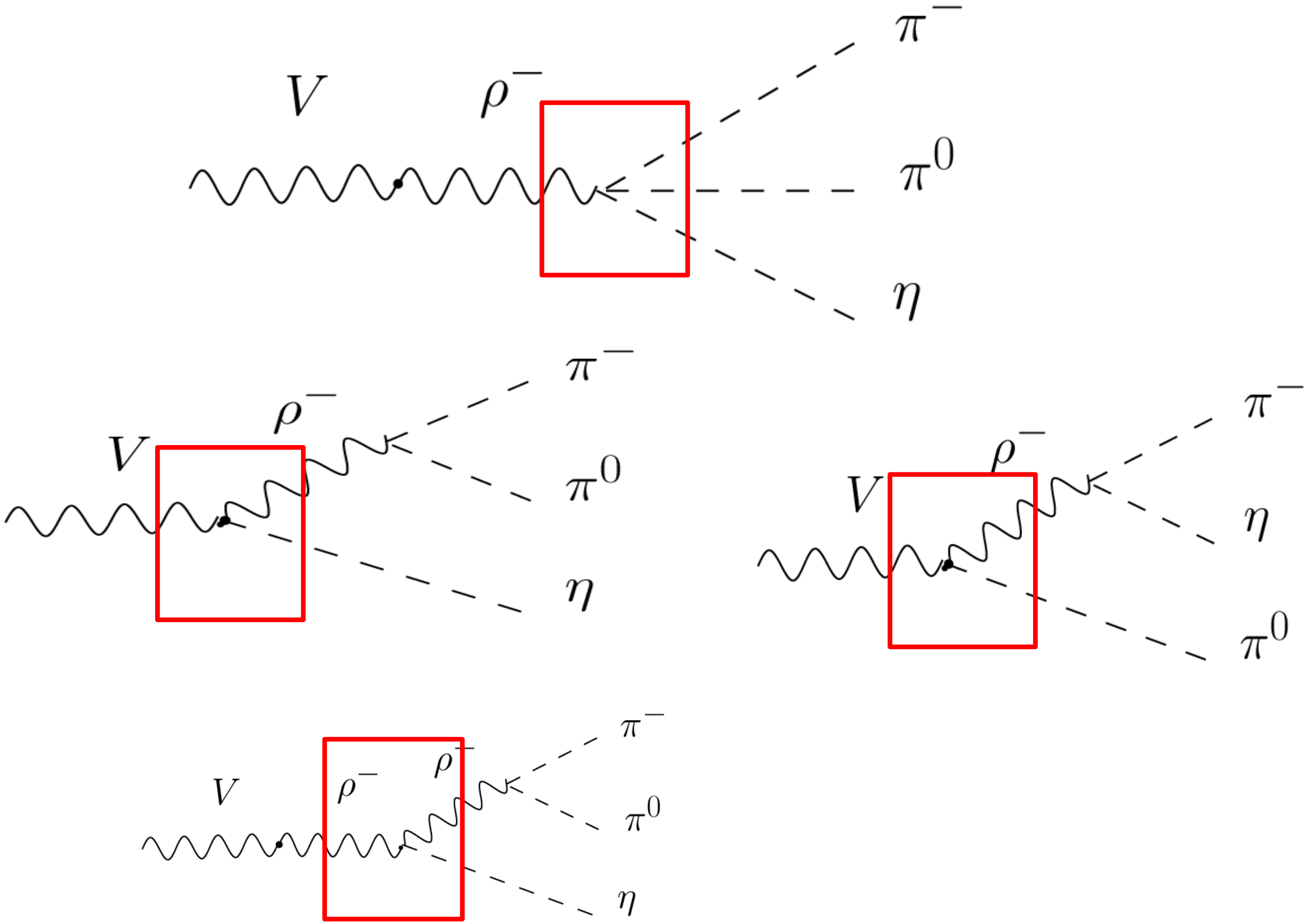
Contribution to Vector form factor

$V=\bar{d}\gamma_\mu u$

1. $V \to \pi^- \pi^0 \eta$
2. $V \to \rho^- \to \pi^- \pi^0 \eta$
3. $V \to$
   - $\rho^- \eta \to \pi^- \pi^0 \eta$
   - $\rho^- \pi^0 \to \pi^- \pi^0 \eta$
4. $V \to$
   - $\rho^- \eta \to \pi^- \pi^0 \eta$
   - $\rho^- \pi^0 \to \pi^- \pi^0 \eta$



IPV interactions in the vector form factor



IPV interactions related to the other processes v=vector meson, π=pseudo-scalar

- **v → π π π** **ρ → π π⁺ π⁻**
- **v → π γ** **ρ → π γ**
- **π → v γ** **η’ → ω γ**
- **π → γ γ** **π → γ γ**

Theoretical Framework

- Chiral Lagrangian with vector mesons
- Including ϕ and η_0 mesons
- Including IPV interactions

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

Intrinsic Parity violating term

$$\mathcal{L} = \sum_{i=1}^{7} C_i^{IPV} \mathcal{L}_i$$

$$\begin{aligned}
\mathcal{L}_1 &= i\epsilon^{\mu\nu\rho\sigma}\mathrm{Tr}[\alpha_{L\mu}\alpha_{L\nu}\alpha_{L\rho}\alpha_{R\sigma} - (R \leftrightarrow L)], \\
\mathcal{L}_2 &= i\epsilon^{\mu\nu\rho\sigma}\mathrm{Tr}[\alpha_{L\mu}\alpha_{R\nu}\alpha_{L\rho}\alpha_{R\sigma}], \\
\mathcal{L}_3 &= -\frac{1}{2}\epsilon^{\mu\nu\rho\sigma}\mathrm{Tr}[F_{V\mu\nu}\{\alpha_{L\rho}\alpha_{R\sigma} - (R \leftrightarrow L)\}], \\
\mathcal{L}_4 &= \epsilon^{\mu\nu\rho\sigma}\mathrm{Tr}(\hat{F}_L + \hat{F}_R)\{\alpha_{L\rho}, \alpha_{R\sigma}\} \\
\mathcal{L}_5 &= \epsilon^{\mu\nu\rho\sigma}F^0_{V\mu\nu}\mathrm{Tr}[\alpha_{L\rho}\alpha_{R\sigma} - (R \leftrightarrow L)] \\
\mathcal{L}_6 &= \frac{\eta_0}{f}\epsilon^{\mu\nu\rho\sigma}\mathrm{Tr}F_{V\mu\nu}F_{V\rho\sigma} \\
\mathcal{L}_7 &= \frac{\eta_0}{f}\epsilon^{\mu\nu\rho\sigma}F^0_{V\mu\nu}F^0_{V\rho\sigma}
\end{aligned}$$

Fit results

C3=0.0974

C4=0.0042

C5=-0.718

C6=-0.340

C7=-4.295

Determining coefficients from V → Pγ, P → V γ, V → V′P

	$\pi^0\gamma$	$\eta\ \ \gamma$	$\eta'\ \ \gamma$
ρ^0	6.0×10^{-4} (1.00264)	3.0×10^{-4} (0.01185)	Br. (theory/experiment)
ω	8.28×10^{-2} (0.00293)	4.6×10^{-4} (0.209766)	
ϕ	1.27×10^{-3} (1.26819)	1.309×10^{-3} (0.127605)	6.25×10^{-5} (1.37306)

	$\rho\ \gamma$	$\omega\ \gamma$
η'	29.1%	2.75% (2.616)

	$\pi^+ \gamma$	$k^0\ \gamma$	$K^+\ \gamma$
ρ^+	4.5×10^{-4} (0.02663)		
K^{0*}		2.46×10^{-3} (0.03311)	
K^{+*}			9.9×10^{-4} (0.019098)

	$\gamma\gamma$
π^0	98.823 % (1.046)
η	39.41 % (0.62054)
η'	2.22 % (0.80117)

	$\omega\ \pi^0$
ϕ	4.7×10^{-5} (1.0)

Numerical results of hadronic mass distribution

We calculate hadronic mass distribution and fit the parameters C_1 , C_2 , C_3 .

Differential branching ratio

Kuhn, Mirkes, Z.Phys.C56,661(1992)

$$dBr(\tau^- \to \eta\pi^-\pi^0\nu_\tau) = \frac{1}{2m_\tau\Gamma_\tau}|\mathcal{M}(\tau^- \to \eta\pi^-\pi^0\nu_\tau)|^2 dPS$$

We compare our model with the experimental data;

$$\frac{\Delta N}{\Delta M} = \frac{N}{Br_{\exp}}\frac{dBr}{dM}$$

where, $M = M_{\pi^0\pi^-}, M_{\pi^0\pi^-\eta}$ ie hadronic invariant mass.

Theory distribution dBr/dM includes the parameters $C_1 - C_2$ and C_3 .

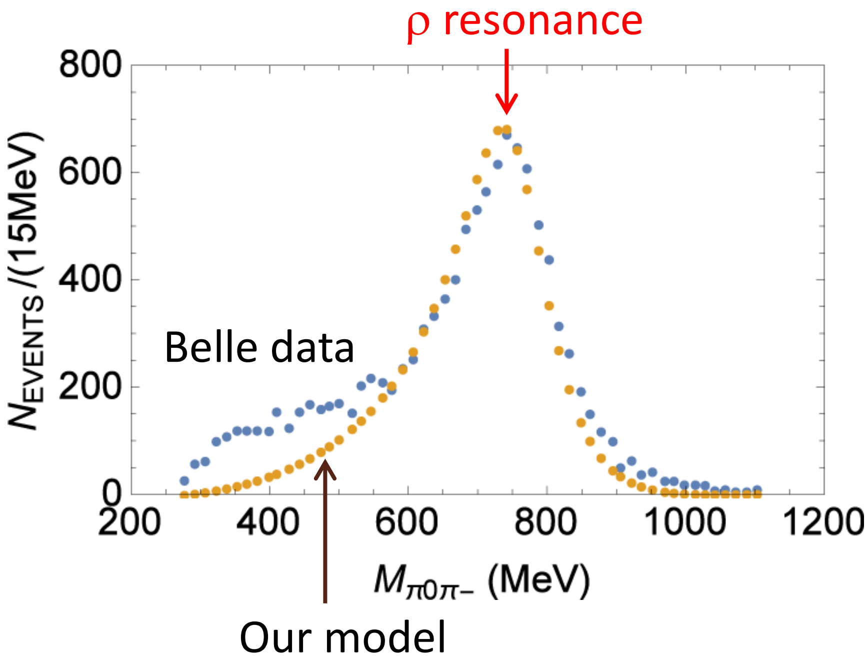
N is the total event number. ΔN and ΔM are the event number in each bin and the bin width, respectively.

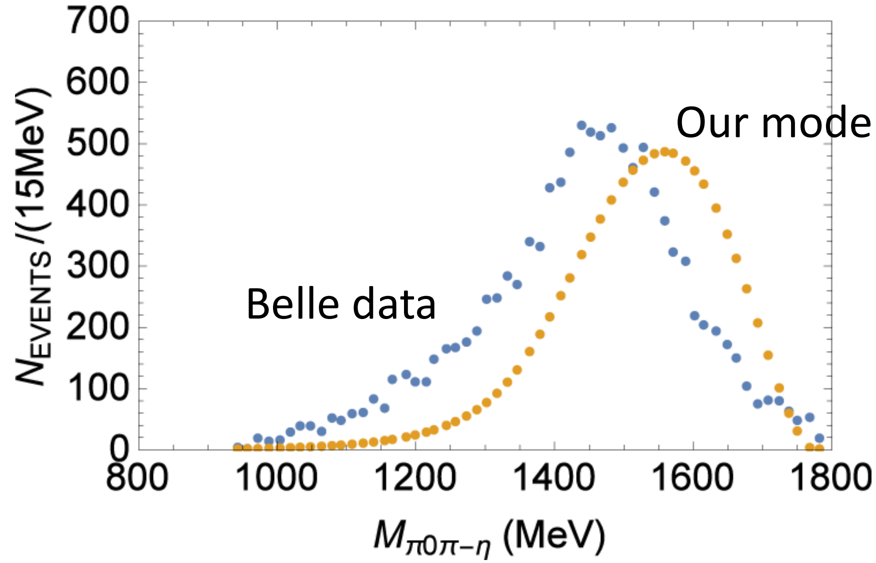
After $C_1 - C_2$ and C_3 are fixed, we obtain the branching ratio.

Hadronic mass distributions (1)

Inami et.al.[Belle]PLB672,209(2009)

We fit our model to $\pi^0 \pi^-$ invariant mass distribution of Belle data.





Parameters are fixed by $C_1 - C_2 = -0.0174$, $C_3 = 0.0485$.

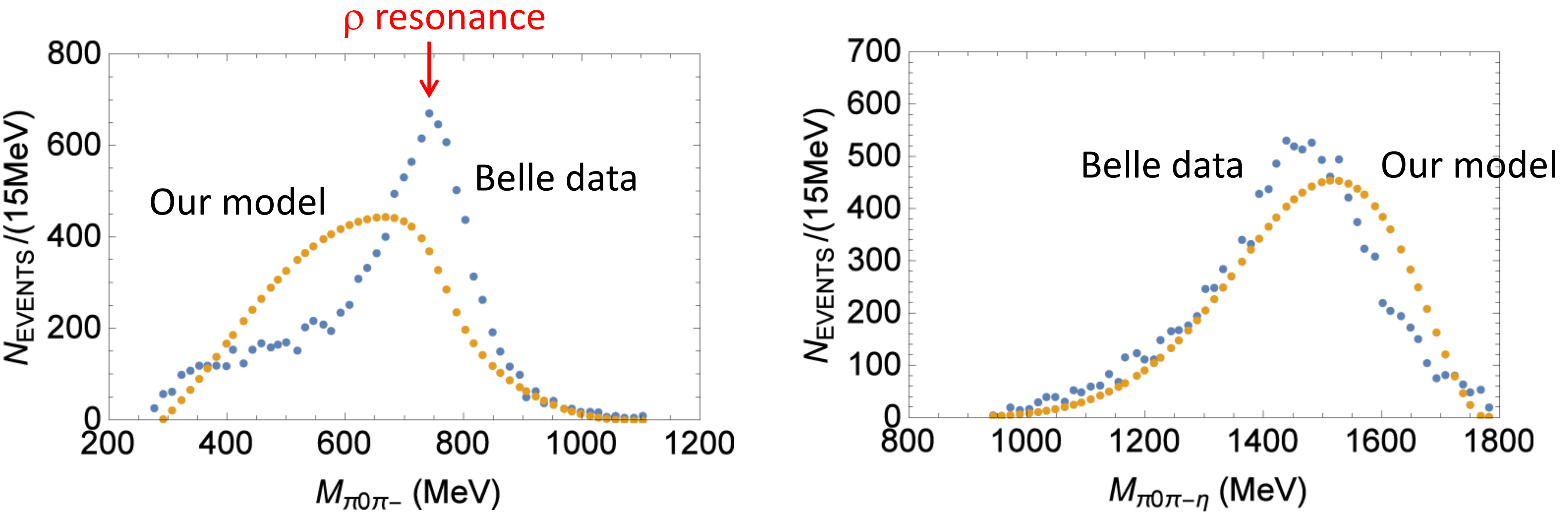
Branching ratio of $\tau^- \to \eta\, \pi^-\, \pi^0\, \nu_\tau$ decay,

Our model (1)	Belle	PDG
1.22×10^{-3}	1.35×10^{-3}	1.39×10^{-3}

Hadronic mass distributions (2)

Inami et.al.[Belle]PLB672,209(2009)

We fit our model to $\pi^0 \pi^- \eta$ invariant mass distribution of Belle data.



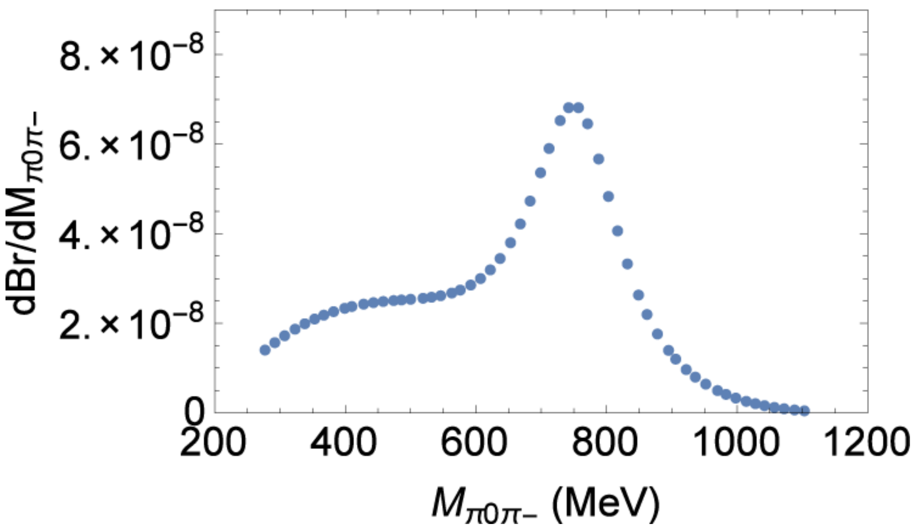
Parameters are fixed by $C_1 - C_2 = 0.0350$, $C_3 = -0.0104$.

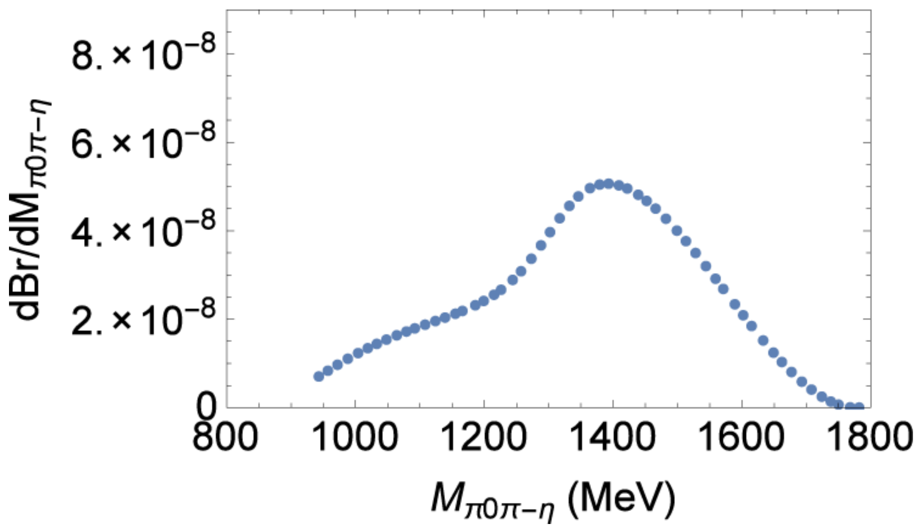
Branching ratio of $\tau^- \to \eta\, \pi^-\, \pi^0\, \nu_\tau$ decay,

Our model (2)	Belle	PDG
1.31×10^{-3}	1.35×10^{-3}	1.39×10^{-3}

Hadronic mass distributions (3)

Hadron invariant mass distribution from axial vector current part





Branching ratio of $\tau^- \to \eta\ \pi^-\ \pi^0\ \nu_\tau$ decay,

Axial vector part	Belle	PDG
2.1×10^{-5}	1.35×10^{-3}	1.39×10^{-3}

5. Summary

- We have studied $\tau^- \to \eta\, \pi^-\, \pi^0\, \nu_\tau$ decay which occurs mainly due to vector current interaction (intrinsic parity violating interaction).

- Taking into account the isospin violation, we determined the mixing matrix of π^0 and η, η'. The contribution to the branching ratio of the axial current interaction part is small, $O(10^{-5}) < Br \simeq 10^{-3}$.

- We calculated the hadronic mass distribution. By fitting the theory distribution to Belle data, we fixed the coefficients $C_1 - C_2$, C_3 of interaction Lagrangian with intrinsic parity violation.

- We also have fixed $C_3 \sim C_7$ by using the other decay modes, e.g. $\rho^+ \to \pi^+ \gamma$, $\omega \to \pi^0 (\eta) \gamma$, $\phi \to \pi^0 (\eta) \gamma$, ….