Pion and Kaon Polarizability Measurements at J-PARC

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and

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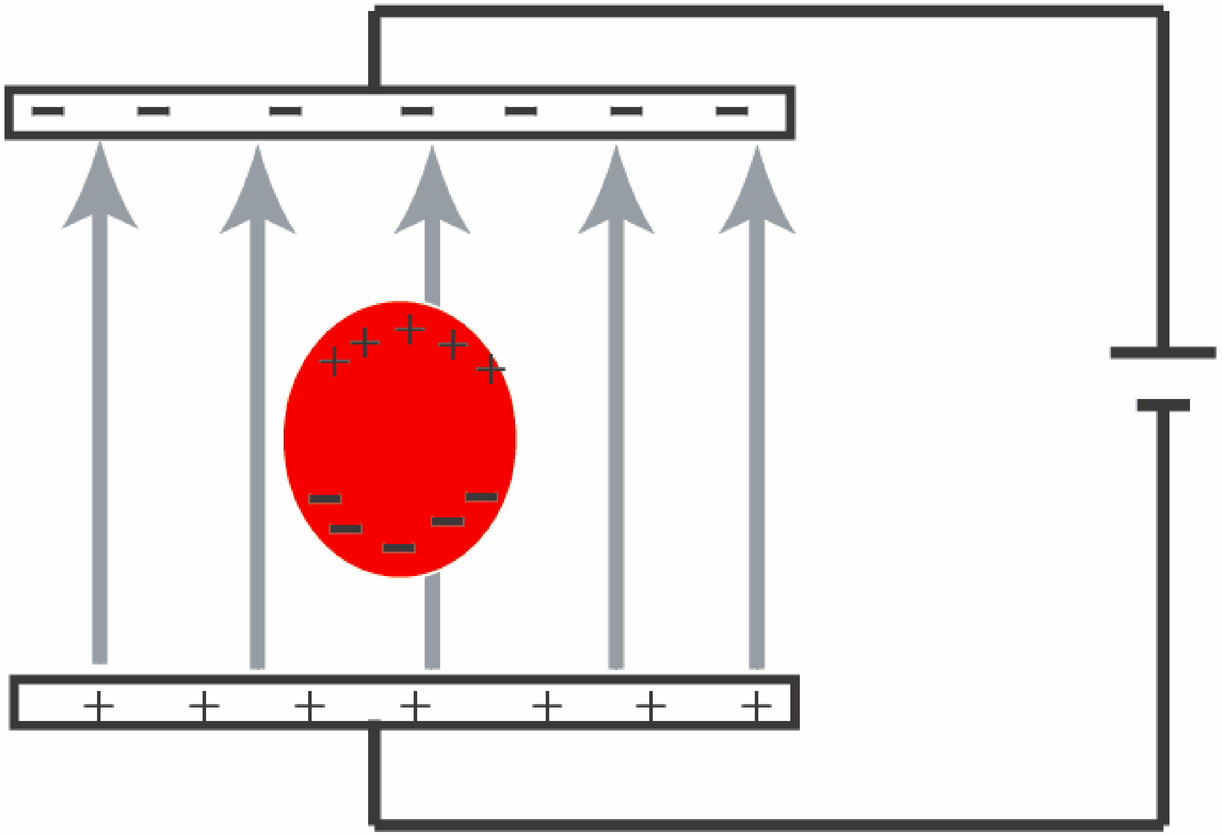
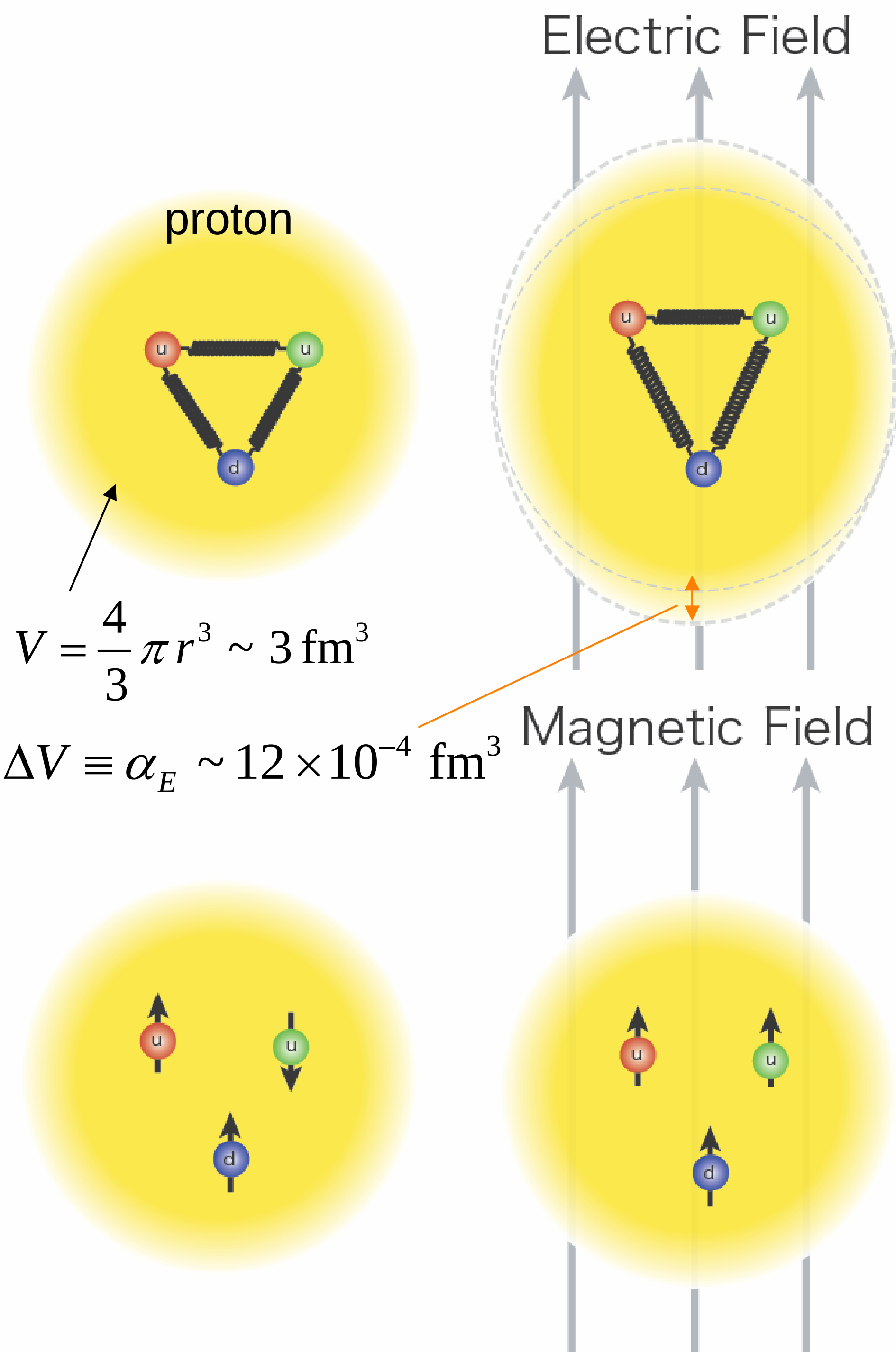
Polarizability

Rigidity response of object to the external electromagnetic field



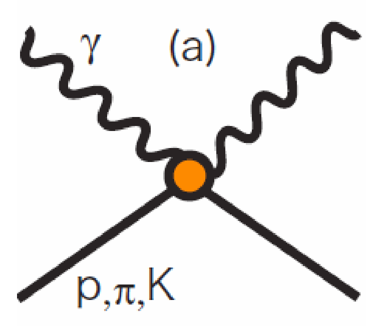
Polarizability:分極率

Polarizability of Proton



$$V = \frac{4}{3}\pi r^3 \sim 3\ \mathrm{fm}^3$$

$$\Delta V \equiv \alpha_E \sim 12 \times 10^{-4}\ \mathrm{fm}^3$$



External Elemag Field

➔ Compton Scattering

Electric Polarizablity

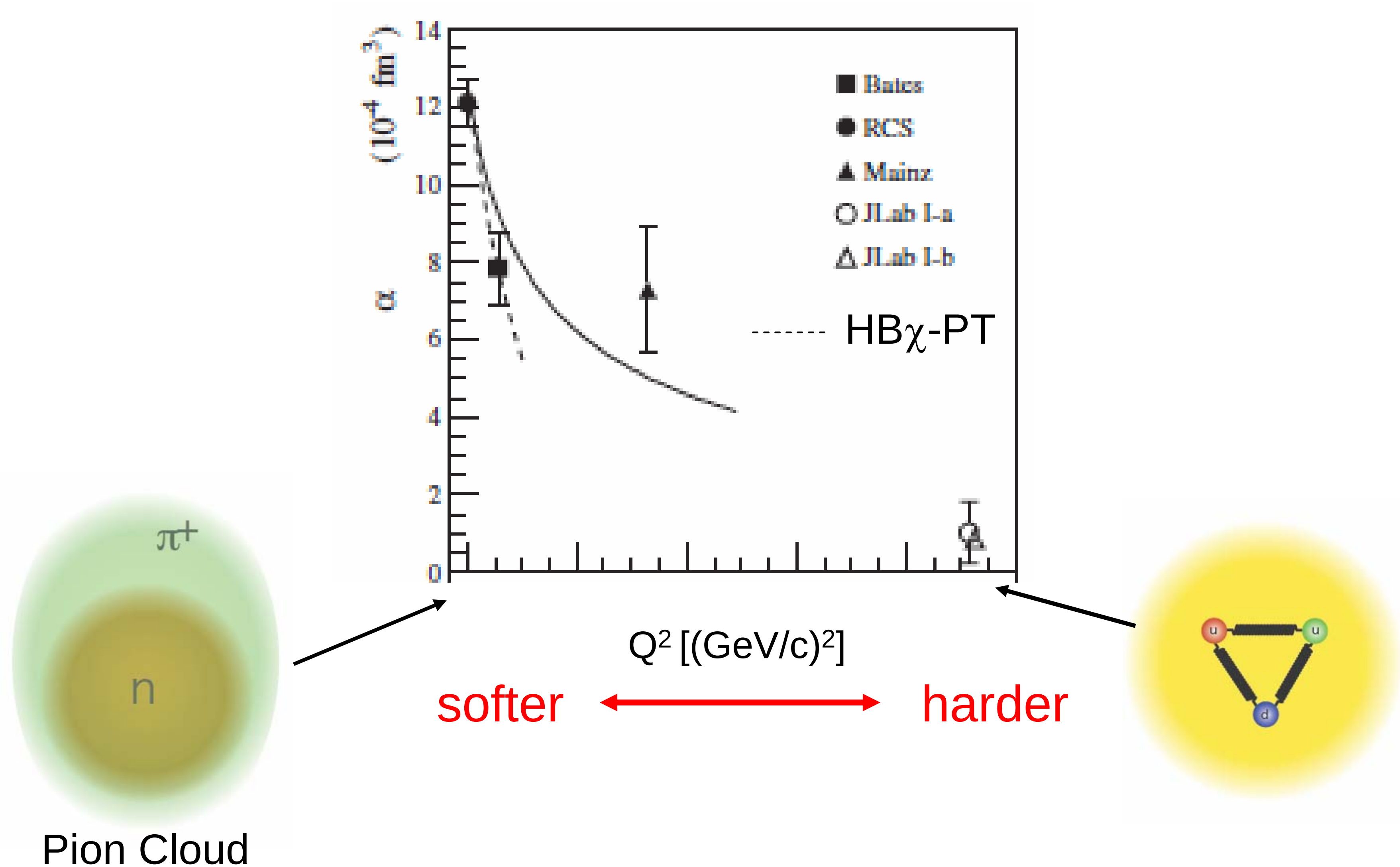
$\mathbf{P}_E = 4\pi\alpha_E\mathbf{E}$

Magnetic Polarizability

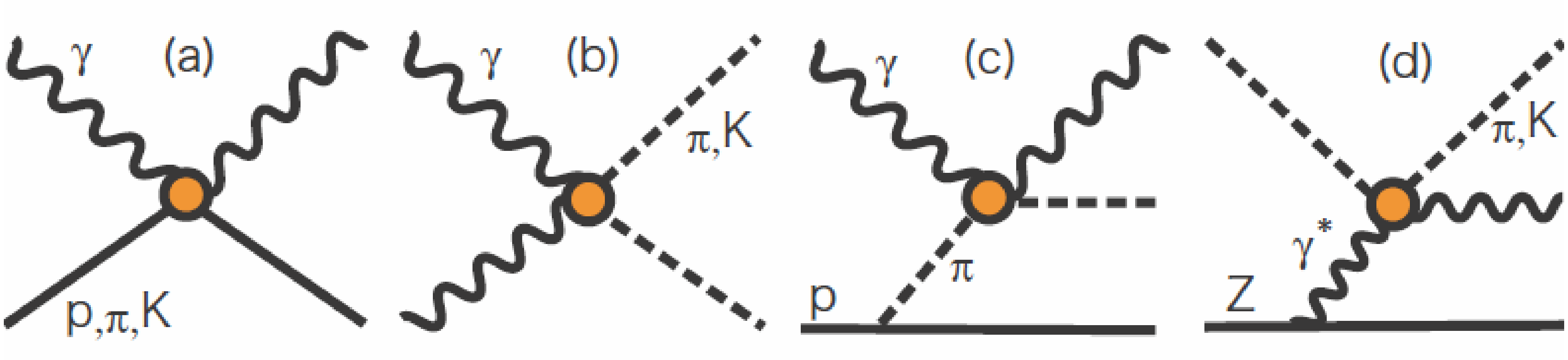
$\mu_M = 4\pi\beta_M\mathbf{H}$

Probes internal structure

Probing Dynamic Response of Object Through Polarizability



Measurement of Meson Polarizabilities



Photon Fusion

Radiative Meson Photo Production

Radiative Meson Scattering

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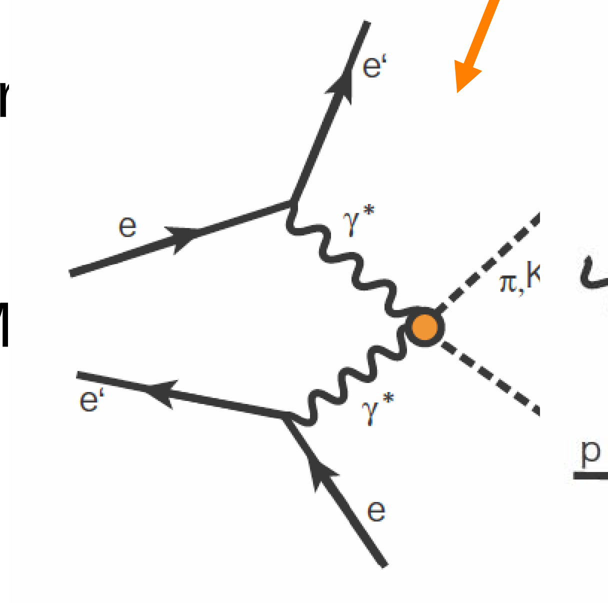
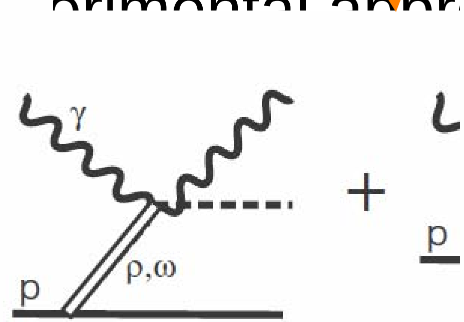
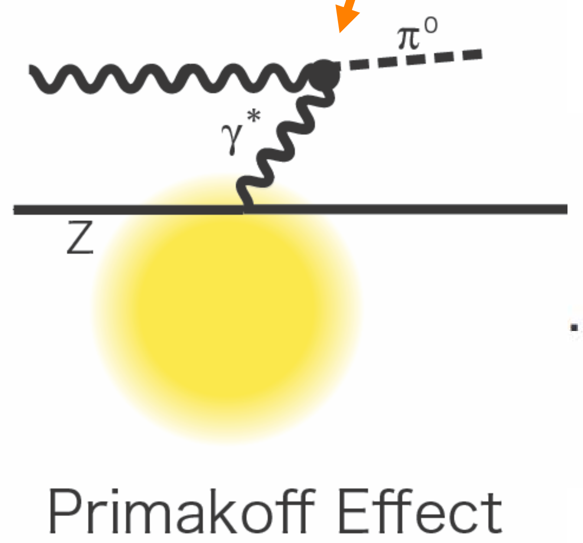
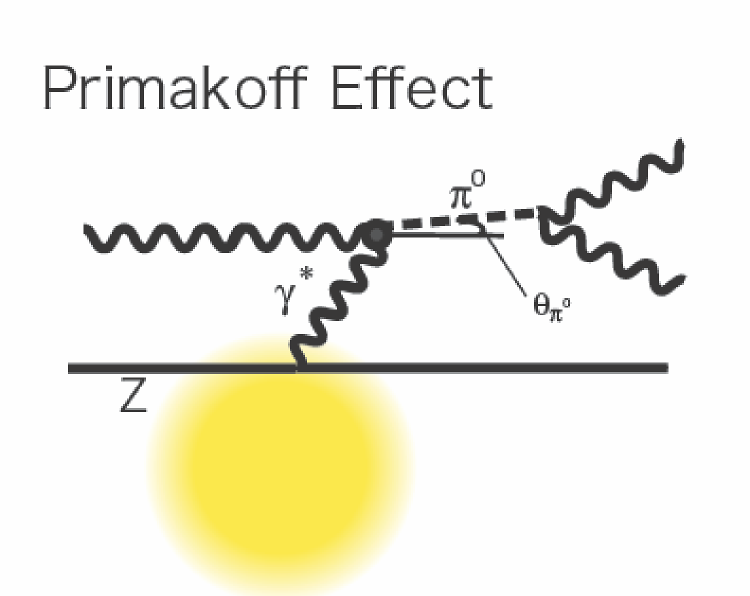




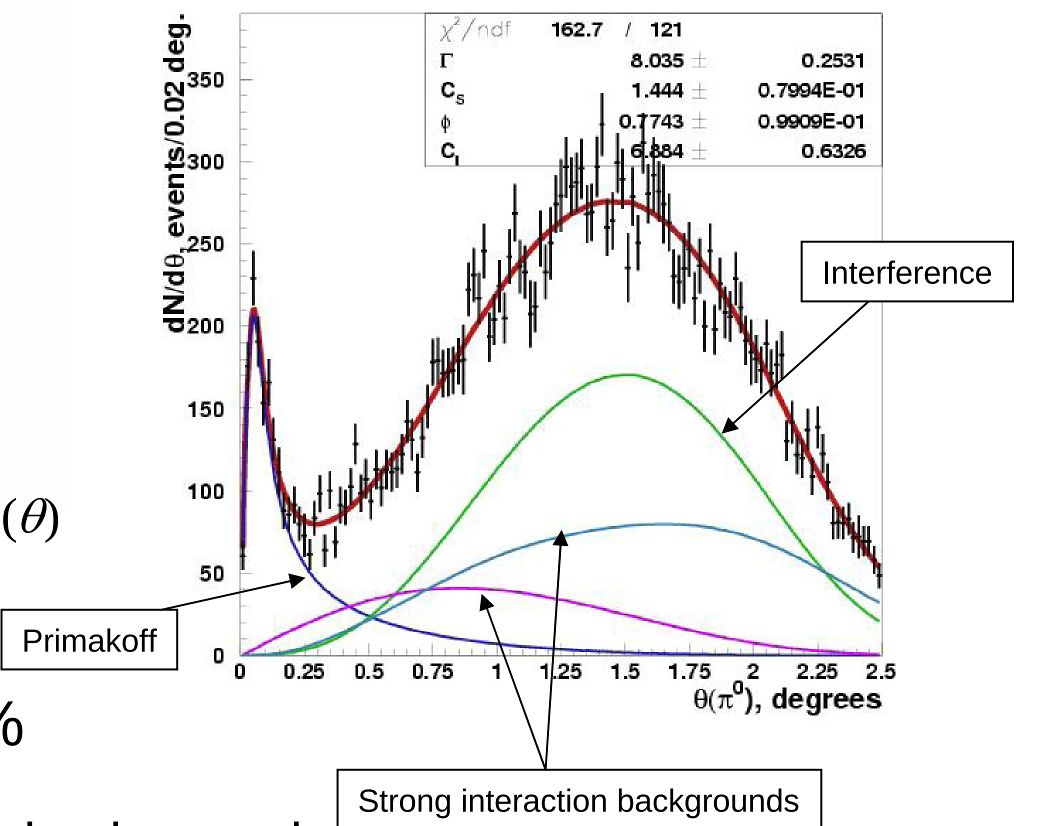


High Precision Experiment Via Primakoff

PrimEx @ JLab



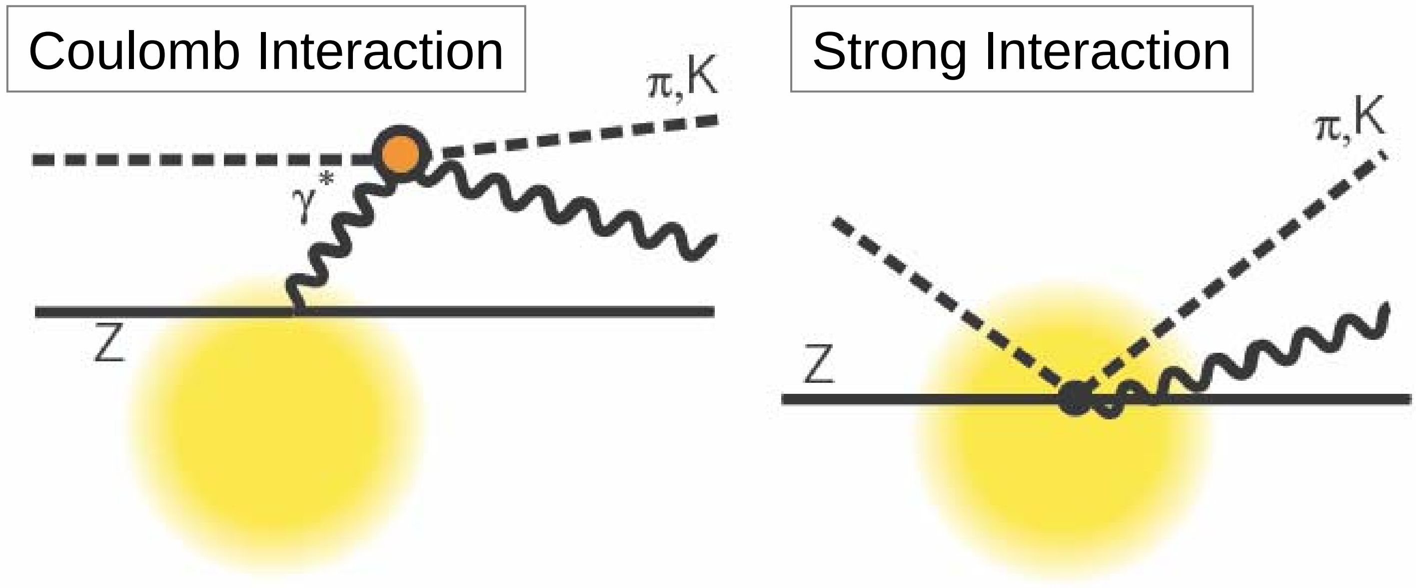
$$\frac{d\sigma_{\text{Primakoff}}}{d\Omega} = \Gamma_{\gamma\gamma} \frac{8\alpha Z^2}{m^3} \frac{\beta^3 E^4}{Q^4} \left|F_{e.m.}(Q)\right|^2 sin^2(\theta)$$



Determine cross section < 2%

Clear separation of Primakoff & background

Radiative Meson Scattering



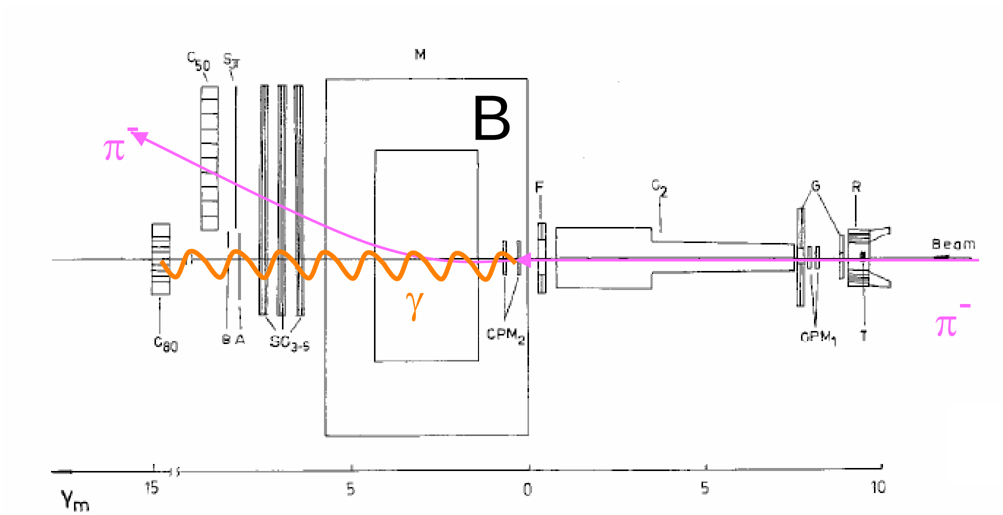
$-t < 10^{-3}\,[(\mathrm{GeV}/c)^2]$ $-t > 10^{-3}\,[(\mathrm{GeV}/c)^2]$

Kinematical Separation of Background and Signal is possible

↓

Golden Channel for Meson Polarizability Measurement

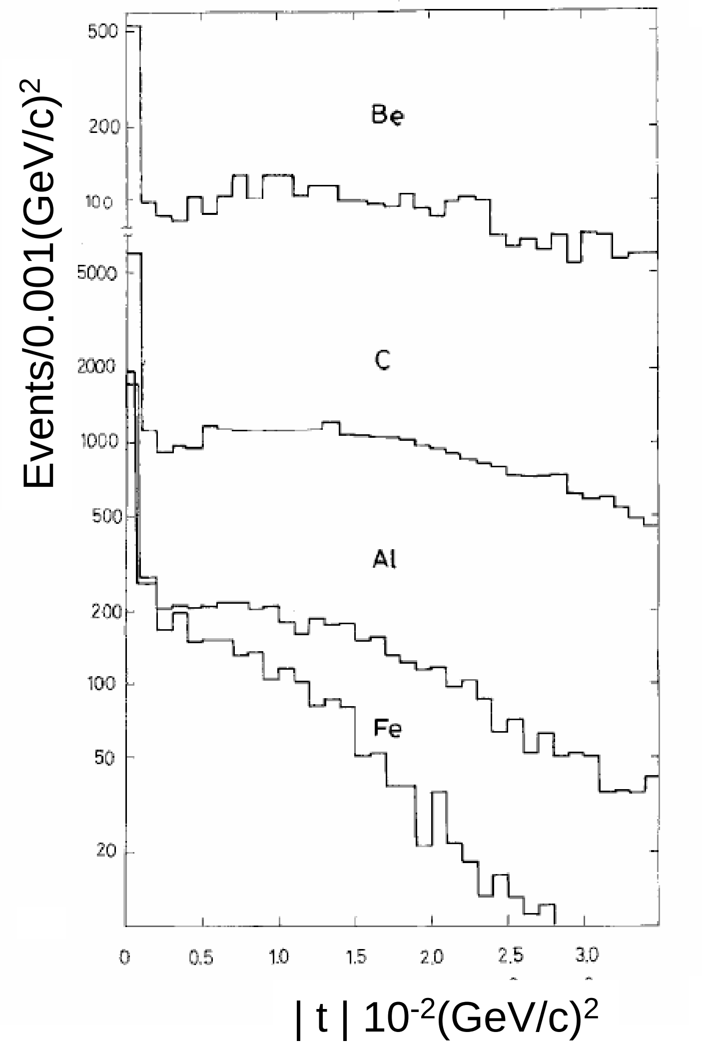
Existing Radiative Meson Scattering Experiment



SIGMA spectrometer @ IHEP, Russia

- E_π = 40GeV
- 60<E_γ<600 MeV
- 2×10^{11} Integrated π^- beam
- 6×10^3 Primakoff events

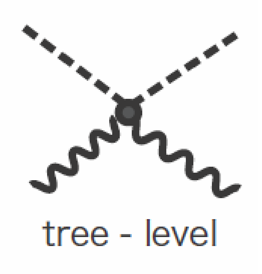
Yu.M. Antipov, et al., Z. Phys. C24 (1984) 39



χPT Predictions

$$Amp(\gamma\pi \to \gamma\pi) = \hat{\varepsilon}_1 \cdot \hat{\varepsilon}_2 \left[-\frac{\alpha}{m_\pi} \left\{ 1 - \frac{1}{6} \langle r_\pi^2 \rangle (q_1^2 + q_2^2) \right\} + \omega_1 \omega_2 \alpha_\pi \right] + \hat{\varepsilon}_1 \times q_1 \cdot \hat{\varepsilon}_2 \times q_2 \beta_\pi$$

$$\alpha_\pi = \frac{4\alpha}{m_\pi F_\pi^2} [L_9 + L_{10}] \qquad \alpha_\pi + \beta_\pi = 0$$



L_9 , L_{10} : Low Energy Constants of Chiral Lagrangian

F_π : Pion Decay Constant

χPT Predictions

$$Amp(\gamma\pi \to \gamma\pi) = \hat{\varepsilon}_1 \cdot \hat{\varepsilon}_2 \left[-\frac{\alpha}{m_\pi} \left\{ 1 - \frac{1}{6} \langle r_\pi^2 \rangle (q_1^2 + q_2^2) \right\} + \omega_1 \omega_2 \alpha_\pi \right] + \hat{\varepsilon}_1 \times q_1 \cdot \hat{\varepsilon}_2 \times q_2 \, \beta_\pi$$

$$\alpha_\pi = \frac{4\alpha}{m_\pi F_\pi^2} [L_9 + L_{10}] \qquad \alpha_\pi + \beta_\pi = 0$$

Reaction	Observable	χ–PT
$\gamma \to \pi^+\pi^-$	$\langle r^2_\pi \rangle$ (fm^2)	$12 L_9 / F_\pi^2$
$\pi^+ \to e^+ \nu_e \gamma$	h_V (m_π^{-1})	$N_C / 12\sqrt{2}\pi^2 F_\pi \Big\|_{N_C=3}$
	h_A / h_V	$32\pi^2 (L_9 + L_{10})$
$\pi^+ \to e^+ \nu_e e^+ e^-$	r_A / h_V	$32\pi^2 L_9$
$\gamma\pi^+ \to \gamma\pi^+$	$(\alpha_\pi + \beta_\pi)$(10^{-4} fm^3)	0
	α_π(10^{-4} fm^3)	$4\alpha/(m_\pi F_\pi^2)(L_9 + L_{10})$

h_A : Axial Structure Constant
h_V : Vector Structure Constant

Chiral SU(2) Predictions and Data

$$\alpha_\pi = \frac{4\alpha}{m_\pi F_\pi^2}\left[L_9 + L_{10}\right]$$

$F_\pi = 92.4 \pm 0.2$ [MeV] : Pion Decay Const.

$\pi^+ \to e^+ \nu_e \gamma$

$$\frac{h_A}{h_V} = 32\pi^2 (L_9 + L_{10}) = 0.46$$

$\alpha_\pi = 2.7 \pm 0.4 \times 10^{-4}$

* Used as input

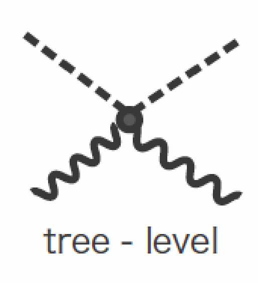
Reaction	Quantity	χ–PT	Exp.
$\gamma \to \pi^+\pi^-$	$\langle r^2_\pi \rangle$ (fm^2)	0.44*	0.44±0.02
$\pi^+ \to e^+\nu_e\gamma$	h_V (m_π^{-1})	0.027	0.029±0.017
	h_A / h_V	0.46*	0.46±0.08
$\pi^+ \to e^+\nu_e e^+ e^-$	r_A/h_V	2.6	2.3±0.6
$\gamma\pi^+ \to \gamma\pi^+$	$(\alpha_\pi+\beta_\pi)(10^{-4}\ fm^3)$	0	1.4±3.1
	$\alpha_\pi(10^{-4}\ fm^3)$	2.7	6.8±1.4

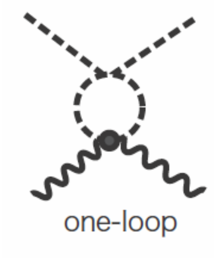
χ-PT has been proven to be very successful in low energy

Higher Order Corrections

J.F.Donoghue, B.R. Holstein, Phys. Rev. D40, 2378(1989)

$$\alpha_\pi = \frac{4\alpha}{m_\pi F_\pi^2}\left[L_9 + L_{10}\right] - \frac{\alpha}{m_\pi}\frac{1}{16\pi^2 F_\pi^2}\left\{1 + F\left(t/m_\pi^2\right)\right\}$$

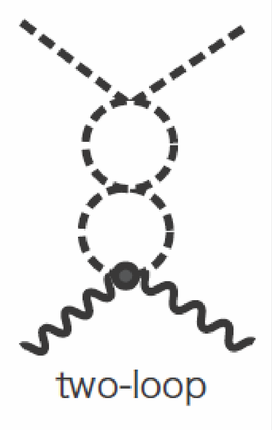




$$F(x) = -\frac{4}{x}\sinh^2\left(\frac{\sqrt{x}}{2}\right) \xrightarrow[x<<1]{} -1 - \frac{x}{12} + \ldots$$

$$\frac{\alpha}{m_\pi}\frac{1}{16\pi^2 F_\pi^2}\left\{1 - 1 - \frac{t}{12 m_\pi^2} - \cdots\right\} \xrightarrow{t\to 0} 0$$

$$\alpha_\pi \xrightarrow{t\to 0} \frac{4\alpha}{m_\pi F_\pi^2}\left[L_9 + L_{10}\right] = (2.7 \pm 0.4) \times 10^{-4}$$



Two-Loop Correction

U. Burgi, Nucl. Phys. B479, 392 (1997))

$$\alpha_\pi = (2.4 \pm 0.5) \times 10^{-4}$$

$$\beta_\pi = (-2.1 \pm 0.5) \times 10^{-4}$$

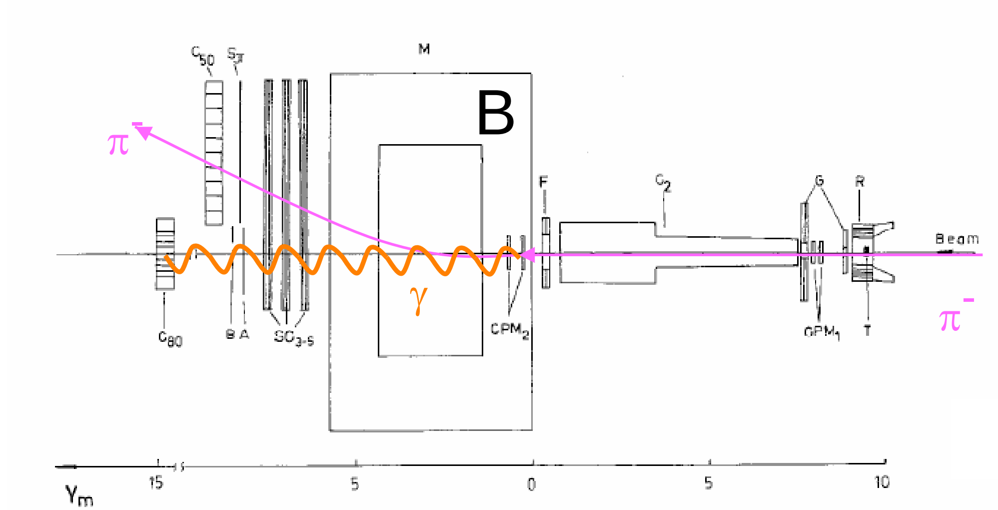
Higher order corrections are predicted to be Small

Existing Data of $\pi^{\pm}$ Polarizabilities

Reaction	Experiment	α_π (10^{-4} fm^3)	$\alpha_\pi - \beta_\pi$ (10^{-4} fm^3)
$\pi^- Z \to \gamma\, \pi^- Z$	IHEP ('83)	6.8±1.4±1.2	
$\gamma p \to \gamma\, \pi^+ n$	Levedev Inst. ('84)	20±12	
	Mainz ('05)		11.6±1.5±3.0±0.5
$\gamma\gamma \to \pi^+\pi^-$	PLUTO ('84)	19.1±4.8±5.7	
	DM 1 ('86)	17.2±4.6	
	DM 2 ('86)	26.3±7.4	
	MARK II ('90)	2.2±1.6	
	MARK II ('93)	2.7	
χ-PT (2-loop)		2.4±0.5	4.4±1.0

- The results from several $\gamma\gamma \to \pi^+\pi^-$ experiments are inconsistent to each other.
- Model dependent extraction from the latest $\gamma p \to \gamma\, \pi^+ n$ (Mainz), disagree w/ χ-PT
- New Primakoff experiment is desired to address this issue

Experimental Requirements



- Similar Setup with Sigma Spectrometer @ IHEP
- E_{π}~40 GeV
  - Boosts Primakoff peak to forward angle (Better separation from backgrounds)
  - Enhances Primakoff amplitude
- Calorimeter at zero degrees
- Coincidence with Calorimeter and Compton scattered pion

Summary

- Pion Polarizability is the one of the most fundamental quantity calculable by χ-PT
- Pion Polarizability is one of few low energy observables for χ-PT still in disagreement w/ exp.
- Present situation raises severe question about our understanding of low-energy QCD.
- New Primakoff experiment at J-PARC using high intensity and high momentum pion/kaon beams is a great opportunity to address this problem.

Backup Slides

γγ−>ππ

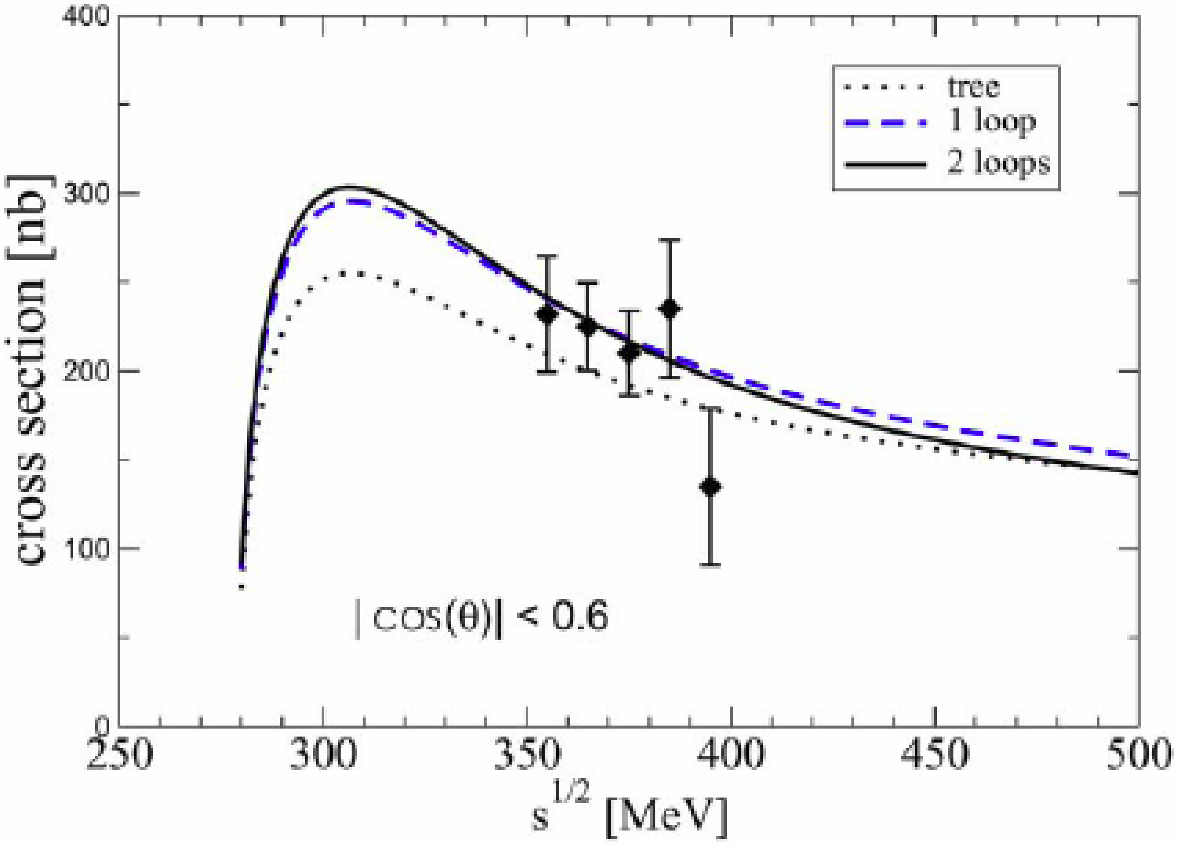


Fig. 6. The $\gamma\gamma \to \pi^+\pi^-$ cross section $\sigma(s; |\cos\theta| \leqslant Z = 0.6)$ as a function of $\sqrt{s}$. The experimental data are taken from [25].

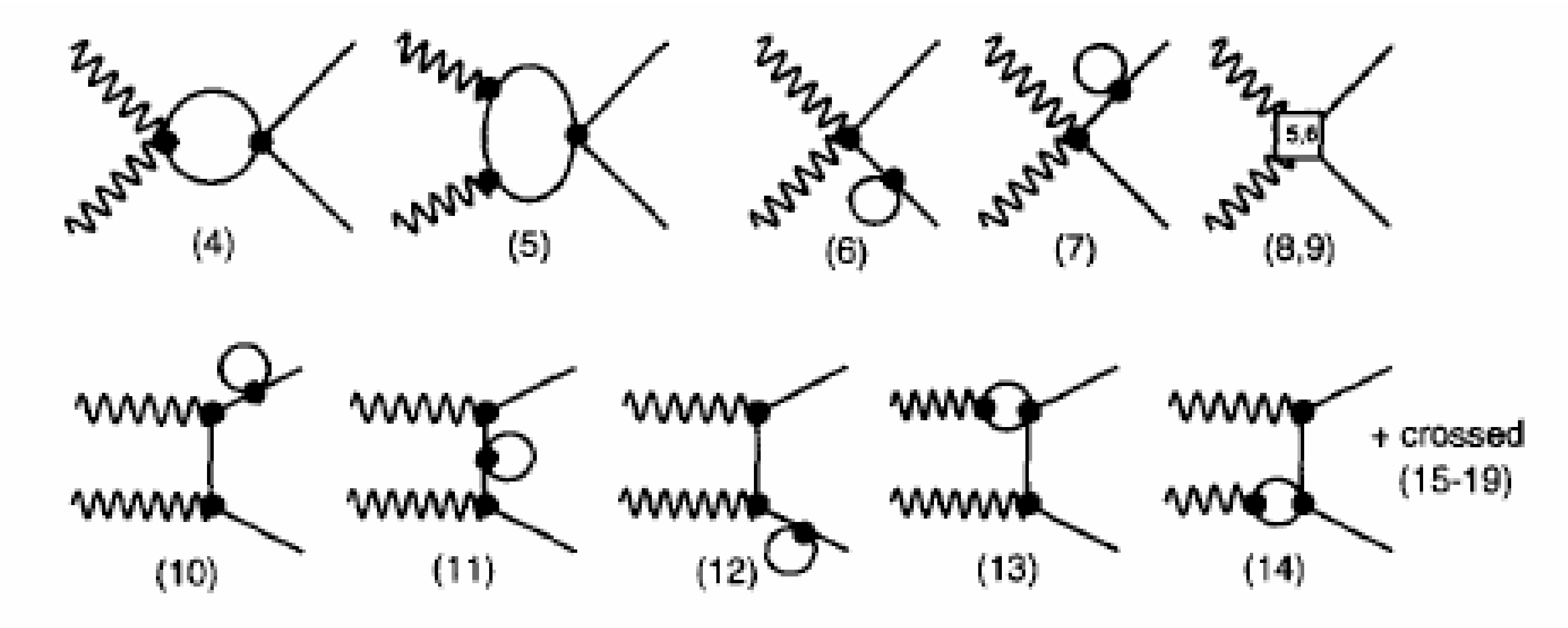
Chiral SU(2)+SU(3) Predictions and Data

Reaction	Quantity	χ–PT	Exp.
$\gamma \rightarrow \pi^+\pi^-$	$\langle r^2_\pi \rangle$ (fm^2)	0.44*	0.44 ± 0.02
$\gamma \rightarrow K^+K^-$	$\langle r^2_K \rangle$ (fm^2)	0.44	0.34 ± 0.05
$\pi^+ \rightarrow e^+\nu_e\gamma$	h_V (m_π^{-1})	0.027	0.029 ± 0.017
	h_A / h_V	0.46*	0.46 ± 0.08
$K^+ \rightarrow e^+\nu_e\gamma$	$(h_A + h_V)$ (m_π^{-1})	0.038	0.043 ± 0.003
$\pi^+ \rightarrow e^+\nu_e e^+ e^-$	r_A / h_V	2.6	2.3 ± 0.6
$\gamma\pi^+ \rightarrow \gamma\pi^+$	$(\alpha_\pi + \beta_\pi)(10^{-4}$ fm$^3)$	0	1.4 ± 3.1
	$\alpha_\pi(10^{-4}$ fm$^3)$	2.7	6.8 ± 1.4
$K \rightarrow \pi e^+\nu_e$	$\xi = f_-(0)/f_+(0)$	-0.13	-0.20 ± 0.08
	λ_+ (m^2)	0.067	0.065 ± 0.005
	λ_- (m^2)	0.040	0.050 ± 0.012

h_A : Axial Structure Constant
h_V : Vector Structure Constant

* Used as input

One-Loop Diagrams @ ChPT



Two-Loop Diagrams @ ChPT

U. Bürgi/Nuclear Physics B 479 (1996) 392–426