Chiral Symmetry and Low-Energy Pion-Photon Reactions

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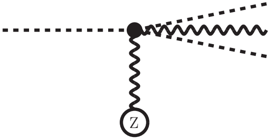
- Tests of Chiral Perturbation Theory via low-energy $\pi^-\gamma$ reactions
- COMPASS@CERN: Primakoff effect to extract $\pi^-\gamma$ cross sections
- π-Compton scattering $\pi^-\gamma \to \pi^-\gamma$: electric/magnetic polarizabilities
- Radiative corrections to π-Compton scattering (and $\mu^\pm p \to \mu^\pm p$)
- Chiral anomaly test: $\pi^-\gamma \to \pi^-\pi^0$
- Neutral and charged pion-pair production: $\pi^-\gamma \to \pi^-\pi^0\pi^0$, $\pi^+\pi^-\pi^-$
- Radiative corrections to $\pi^-\gamma \to 3\pi$
- Radiative corrections to proton and neutron magnetic moments

COMPASS experiment at CERN (S. Paul, J. Friedrich, B. Ketzer, B. Grube,...)

Primakoff effect:



- Scattering high-energy pions in nuclear Coulomb field (charge Z) allows to extract cross sections for $\pi^-\gamma$ reactions (equivalent-photon method)

$$\frac{d\sigma}{ds\,dQ^2} = \frac{Z^2\alpha}{\pi(s-m_\pi^2)}\,\frac{Q^2-Q^2_{min}}{Q^4}\,\sigma_{\pi^-\gamma}(s)\,, \qquad Q_{min} = \frac{s-m_\pi^2}{2E_{beam}}$$

- $s = (\pi^-\gamma \text{ invariant mass})^2$, $Q \to 0$ momentum transfer by virtual photon
- Isolate Coulomb peak from strong interaction background
- Different final-states $\pi^-\gamma$, $\pi^-\pi^0$, $\pi^-\pi^0\pi^0$, $\pi^+\pi^-\pi^-$ allow to test different aspects of chiral dynamics (low-energy QCD)
- Diffractive pion-scattering: meson spectroscopy and search for exotics

Structure of pion at low energies: calculated in chiral perturbation theory

- General form of pion Compton-scattering amplitude in cm frame:

$$T_{\pi\gamma} = 8\pi\alpha\Big\{ -\vec{\epsilon}_1\cdot\vec{\epsilon}_2\,A(s,t) + \vec{\epsilon}_1\cdot\vec{k}_2\,\vec{\epsilon}_2\cdot\vec{k}_1\,\frac{2}{t}\Big[A(s,t)+B(s,t)\Big]\Big\}, \quad t=(k_1-k_2)^2$$

- Corresponding differential cross section:

$$\frac{d\sigma}{d\Omega_{cm}} = \frac{\alpha^2}{2s}\Big\{|A(s,t)|^2 + |A(s,t)+(1+\cos\theta_{cm})B(s,t)|^2\Big\}$$

- Tree diagrams (s-channel pole diagram vanishes, $\epsilon_1\cdot(2p_1+k_1)=0$):

$$A(s,t)=1, \qquad B(s,t)=\frac{s-m_\pi^2}{m_\pi^2-s-t}$$

- One-loop diagrams (finite after mass renormalization):

$$A(s,t) = -\frac{1}{(4\pi f_\pi)^2}\Big\{\frac{t}{2} + 2m_\pi^2 \ln^2\frac{\sqrt{4m_\pi^2-t}+\sqrt{-t}}{2m_\pi}\Big\} \sim t^2 > 0$$

- Electric/magnetic polarizabilities = low-energy const. with $\alpha_\pi + \beta_\pi = 0$

$$A(s,t) = -\frac{\beta_\pi m_\pi t}{2\alpha} < 0, \qquad \alpha_\pi - \beta_\pi = \frac{\alpha(\bar{\ell}_6-\bar{\ell}_5)}{24\pi^2 f_\pi^2 m_\pi}$$

- Combination $\bar{\ell}_6 - \bar{\ell}_5 = 3.0 \pm 0.3$ determined via radiative pion decay $\pi^+ \to e^+\nu_e\gamma$, PIBETA@PSI: axial-to-vector coupl. ratio $F_A/F_V = 0.44$

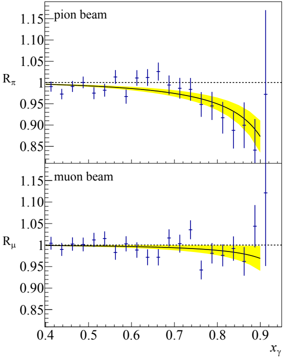
Pion polarizability measurement

- Two-loop prediction of chiral perturbation theory [J. Gasser et al. ('06)]

$$\alpha_\pi - \beta_\pi = \frac{\alpha(\bar\ell_6 - \bar\ell_5)}{24\pi^2 f_\pi^2 m_\pi} + \frac{\alpha m_\pi}{(4\pi f_\pi)^4}\Big\{c^r + \frac{8}{3}\Big(\bar\ell_2 - \bar\ell_1 + \bar\ell_5 - \bar\ell_6 + \frac{65}{12}\Big)\ln\frac{m_\pi}{m_\rho} + \frac{4}{9}(\bar\ell_1 + \bar\ell_2) - \frac{\bar\ell_3}{3} + \frac{4\bar\ell_4}{3}(\bar\ell_6 - \bar\ell_5) - \frac{187}{81} + \Big(\frac{53\pi^2}{48} - \frac{41}{324}\Big)\Big\}$$

$$\alpha_\pi - \beta_\pi = (5.7 \pm 1.0)\cdot 10^{-4}\,\mathrm{fm}^3\,, \qquad \alpha_\pi + \beta_\pi = 0.16\cdot 10^{-4}\,\mathrm{fm}^3$$

- COMPASS result: $\alpha_\pi - \beta_\pi = (4.0 \pm 1.8)\cdot 10^{-4}\,\mathrm{fm}^3$ [PRL 114, 062002 ('15)]



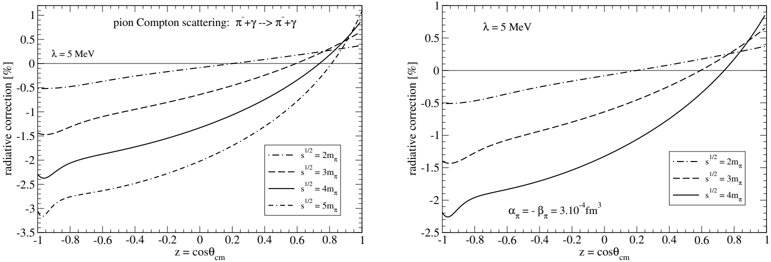
$x_\gamma = E_\gamma/E_\pi$ in lab, $\cos\theta_{\rm cm} = 1 - 2x_\gamma s/(s - m_\pi^2)$

Analysis of data includes:

- chiral pion-loop corrections $A(s,t) \sim \ln^2(.t.)$
- radiative corrections [NPA 812, 186 ('08)]
- isospin-breaking correction $\sim (m_\pi^2 - m_{\pi^0}^2)\ln^2(.t.)$
- previous results from Mainz and Serpukhov: $\alpha_\pi - \beta_\pi = (12 - 16)\cdot 10^{-4}\,\mathrm{fm}^3$

Radiative corrections to pion Compton scattering

- Pion-structure effects small: necessary to include radiative corr. of $\mathcal{O}(\alpha)$
- Start with structureless pion: extensive exercise in one-loop scalar QED
- Include leading pion-structure $\alpha_\pi - \beta_\pi$ in form of $\gamma\gamma$-contact vertex $F_{\mu\nu}F^{\mu\nu}$
- Virtual photon loops + soft γ-radiation ($\omega < \lambda$) give infrared finite result

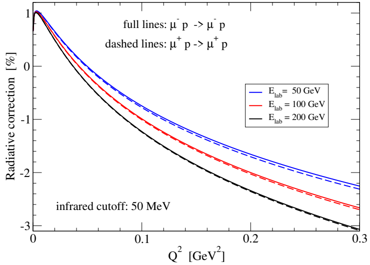


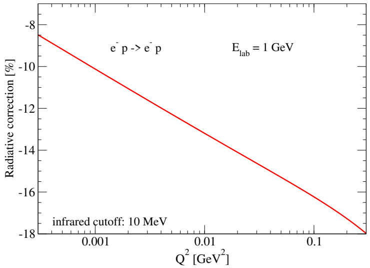
- QED radiative corrections are maximal in backward directions $z \simeq -1$
- Same kinematical signature as pion polarizability difference $\alpha_\pi - \beta_\pi$
- Suppressed by factor of ~ 10
- Relative size and angular depend. not affected by leading pion-structure

- COMPASS proposal [S. Paul, J. Friedrich, et al.]:
  Measure proton charge radius $r_p = (0.84 - 0.88)$ fm in $\mu^\pm p \to \mu^\pm p$ scatter.
- Generalize Rosenbluth formula to massive muons ($m_\mu \geq \sqrt{-t} = Q$)

$$\frac{d\sigma^{(1\gamma)}}{dt} = \frac{4\pi\alpha^2}{t^2}\left[s-(M_p+m_\mu)^2\right]^{-1}\left[s-(M_p-m_\mu)^2\right]^{-1} \times\left\{\left[\frac{(s+M_p^2-m_\mu^2)^2}{4M_p^2-t}+m_\mu^2-s\right]\left[4M_p^2 G_E^2(t)-t\,G_M^2(t)\right]+t\left(m_\mu^2+\frac{t}{2}\right)G_M^2(t)\right\}$$

- Advantage of muons over electrons: much smaller radiative corrections





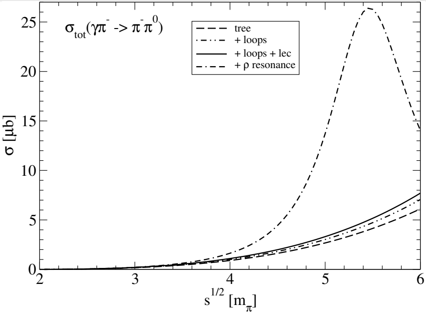
- Analytical calculation of radiative corrections done for point-like proton:
  Vertex corrections, vacuum polarization, 2-photon exchange, soft bremsstrahlung

Extracting the chiral anomaly

- $\pi^0 \to 2\gamma$ and $\gamma \to 3\pi$ couplings determined by chiral anomaly of QCD
- Amplitude and cross section for $\pi^-(p_1) + \gamma(k,\epsilon) \to \pi^-(p_2) + \pi^0(p_0)$:

$$T_{\gamma 3\pi} = \frac{e}{4\pi^2 f_\pi^3} \epsilon_{\mu\nu\kappa\lambda} \epsilon^\mu p_1^\nu p_2^\kappa p_0^\lambda \, M(s,t)\,, \qquad F_{3\pi} = 9.8\,\mathrm{GeV}^{-3}$$

$$\sigma_{tot}(s) = \frac{\alpha(s-m_\pi^2)(s-4m_\pi^2)^{3/2}}{(4f_\pi)^6 \pi^4 \sqrt{s}} \int_{-1}^{1} dz\,(1-z^2)\,|M(s,t)|^2$$



- $\rho(770)$-resonance must be included:

$$M(s,t)^{(\rho)} = 1 + 0.46 \left\{ \frac{s}{m_\rho^2 - s - i\sqrt{s}\,\Gamma_\rho(s)} + \frac{t}{m_\rho^2 - t} + \frac{u}{m_\rho^2 - u} \right\}$$

Extracting the chiral anomaly

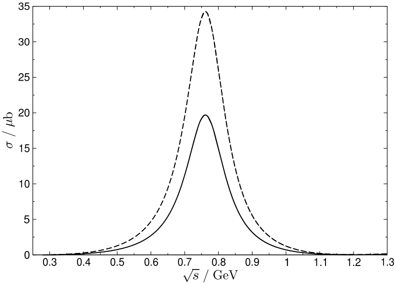
- Dispersive representation of $\pi\gamma \to \pi\pi$ with p-wave phase shift as input [M. Hoferichter, B. Kubis, D. Sakkas, PRD 86, 116009 ('12)]

$$\frac{e}{4\pi^2 f_\pi^3} M(s,t) = F(s) + F(t) + F(u)\,, \qquad u = 3m_\pi^2 - s - t\,,$$

$$F(s) = a + b\,s + \frac{s^2}{\pi}\int_{4m_\pi^2}^{\infty} ds' \frac{\mathrm{Im}F(s')}{s'^2(s'-s)}\,, \quad \mathrm{Im}F(s) = [F(s) + \hat{F}(s)]\sin\delta_1^1(s)e^{-i\delta_1^1(s)}$$

- Relevant subtraction constant $C = 3(a + b\,m_\pi^2)$ is fitted to data and matched via the chiral representation to $F_{3\pi}$

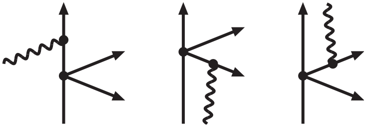
$$C = F_{3\pi}\left\{1 + \frac{m_\pi^2}{(4\pi f_\pi)^2}\left(2.9 - \ln\frac{m_\pi}{m_\rho}\right)\right\} = 1.067\,F_{3\pi}$$

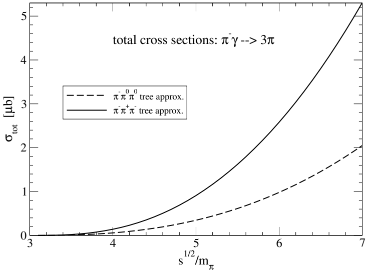


- solid line: $C = 9.78\,\mathrm{GeV}^{-3}$
  dashed line: $C = 12.9\,\mathrm{GeV}^{-3}$
- close to threshold, one-photon exchange an important correction: $1 \to 1 - 2e^2 f_\pi^2/t$
- Good theory waiting for good data

Tree level cross sections for $\pi^-\gamma \to 3\pi$

- Coulomb gauge $\epsilon \cdot p_1 = \epsilon \cdot k = 0$, photon does not couple to incoming π^-
- No $\gamma 4\pi$ vertex at leading order





- Example: total cross section for $\pi^-(p_1) + \gamma(k,\epsilon) \to \pi^-\pi^0\pi^0$

$$\sigma_{tot}(s) = \frac{\alpha}{16\pi^2 f_\pi^4 (s-m_\pi^2)^3} \int_{2m_\pi}^{\sqrt{s}-m_\pi} d\mu \sqrt{\mu^2 - 4m_\pi^2}\, (\mu^2 - m_\pi^2)^2$$
$$\left\{ (s + m_\pi^2 - \mu^2) \ln \frac{s + m_\pi^2 - \mu^2 + \lambda^{1/2}(s,\mu^2,m_\pi^2)}{2m_\pi\sqrt{s}} - \lambda^{1/2}(s,\mu^2,m_\pi^2) \right\}$$

- $(\mu^2 - m_\pi^2)/f_\pi^2$ is LO chiral $\pi\pi$-interaction, rest from 3-body phase space
- How large are next-to-leading order corrections from chiral loops + cts?

Neutral pion-pair production

- 3-body process: $\pi^-(p_1) + \gamma(k, \epsilon) \to \pi^-(p_2) + \pi^0(q_1) + \pi^0(q_2)$
- General form of T-matrix (in Coulomb gauge)

$$T_{\gamma 4\pi} = \frac{2e}{f_\pi^2}\left[\vec{\epsilon}\cdot\vec{q}_1\, A_1 + \vec{\epsilon}\cdot\vec{q}_2\, A_2\right], \qquad A_2 = A_1\big|(s_1 \leftrightarrow s_2, t_1 \leftrightarrow t_2)$$

- Amplitudes A_1 and A_2 depend on five (independ.) Mandelstam variables:

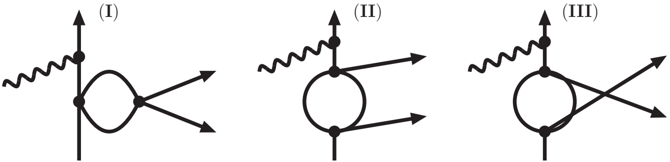
$$s = (p_1 + k)^2, \;\; s_1 = (p_2 + q_1)^2, \;\; s_2 = (p_2 + q_2)^2, \;\; t_1 = (q_1 - k)^2, \;\; t_2 = (q_2 - k)^2$$

- Convenient for permutation of identical neutral pions ($s_1 \leftrightarrow s_2$, $t_1 \leftrightarrow t_2$)
- Tree-level amplitudes:

$$A_1^{(\mathrm{tree})} = A_2^{(\mathrm{tree})} = \frac{2m_\pi^2 + s - s_1 - s_2}{3m_\pi^2 - s - t_1 - t_2}$$

Chiral corrections: [N. Kaiser, NPA 848, 198 ('10)]
Radiative correct.: [EPJA 46, 373 ('10); N.K. + S. Petschauer, EPJA 49, 159 ('13)]

- Pion-loop corrections (example I)

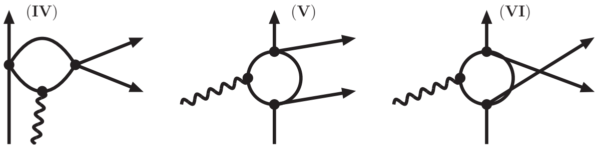


$$A_1^{(\mathrm{I})} = \frac{1}{(4\pi f_\pi)^2}\frac{2m_\pi^2+s-s_1-s_2}{3m_\pi^2-s-t_1-t_2}\Bigg\{\left(\xi+\ln\frac{m_\pi}{\mu}\right)(s_1+s_2+t_1+t_2-11m_\pi^2) +(s_1+s_2+t_1+t_2-7m_\pi^2)\left[J(3m_\pi^2+s-s_1-s_2)-\frac{1}{2}\right]\Bigg\}$$

- Loop function (from loop with two pion-propagators)

$$J(s)=\sqrt{\frac{s-4m_\pi^2}{s}}\left[\ln\frac{\sqrt{|s-4m_\pi^2|}+\sqrt{|s|}}{2m_\pi}-\frac{i\pi}{2}\theta(s-4m_\pi^2)\right],\quad s<0 \;\;\text{or}\;\; s>4m_\pi^2$$

- Pion-loop corrections (example IV)



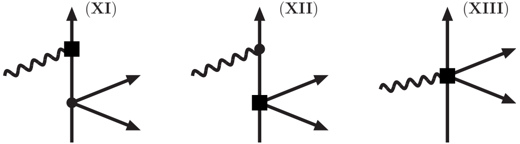
$$A_1^{(\mathrm{IV})} = \frac{2m_\pi^2+s-s_1-s_2}{(4\pi f_\pi)^2}\Bigg\{\xi+\ln\frac{m_\pi}{\mu}-\frac{1}{2}+J(3m_\pi^2+s-s_1-s_2) + \frac{m_\pi^2-s}{2m_\pi^2-t_1-t_2}+\frac{2(s-m_\pi^2)}{(2m_\pi^2-t_1-t_2)^2}\Big\{(s_1+s_2-s-m_\pi^2-t_1-t_2) \times\Big[J(m_\pi^2+s-s_1-s_2+t_1+t_2)-J(3m_\pi^2+s-s_1-s_2)\Big] +2m_\pi^2\Big[G(m_\pi^2+s-s_1-s_2+t_1+t_2)-G(3m_\pi^2+s-s_1-s_2)\Big]\Big\}\Bigg\}$$

- Loop function (from loop with three pion-propagators)

$$G(s) = \left[\ln\frac{\sqrt{|s-4m_\pi^2|}+\sqrt{|s|}}{2m_\pi}-\frac{i\pi}{2}\theta(s-4m_\pi^2)\right]^2, \quad s<0 \ \text{or}\ s>4m_\pi^2$$

Neutral pion-pair production

- Corrections from chiral counterterms: higher-dimensional operators, incorporate unresolved short-distance dynamics of Goldstone bosons



- Complete counterterm contribution:

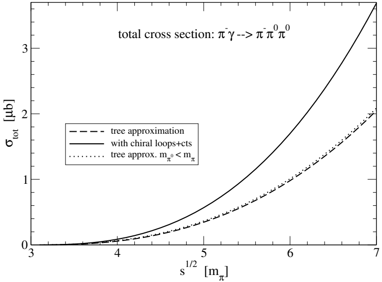
$$A_1^{(\mathrm{ct})} = \frac{1}{(4\pi f_\pi)^2}\frac{1}{3m_\pi^2 - s - t_1 - t_2}\Big\{\frac{\bar\ell_1}{3}(s_1+s_2-s-m_\pi^2)^2 + \frac{\bar\ell_2}{3}\Big[s^2+s_1^2+s_2^2 + t_2^2 - 2ss_1 + (s-2s_1+2s_2-t_1)t_2 + m_\pi^2(s-6s_2+t_1-2t_2+6m_\pi^2)\Big] - \frac{\bar\ell_3}{2}m_\pi^4 + 2\bar\ell_4 m_\pi^2(s+2m_\pi^2-s_1-s_2)\Big\}$$

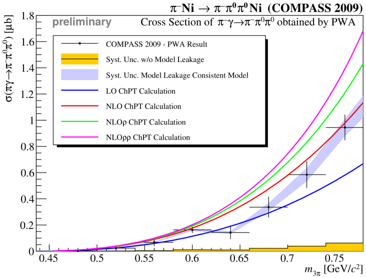
- Values of low-energy constants: $\bar\ell_1 = -0.4\pm0.6$, $\bar\ell_2 = 4.3\pm0.1$, $\bar\ell_3 = 2.9\pm2.4$, $\bar\ell_4 = 4.4\pm0.2$, determined with improved empirical input
- Uncertainty induced by errorbars of $\bar\ell_j$: about $\pm5\%$ for $\sigma_{\mathrm{tot}}(s)$, mainly $\bar\ell_1$
- Chiral <u>resonance</u> amplitudes for $\gamma^*\to4\pi$ [Ecker+Unterdorfer, EPJC 24, 535 ('02)]

Neutral pion-pair production

- Total cross section for $\pi^- \gamma \to 3\pi$

$$\sigma_{\rm tot}(s) = \frac{\alpha}{32\pi^3 f_\pi^4 (s - m_\pi^2)} \iint_{z^2<1} d\omega_1 d\omega_2 \int_{-1}^{1} dx \int_0^\pi d\phi \, |\hat{k} \times (\vec{q}_1 A_1 + \vec{q}_2 A_2)|^2$$



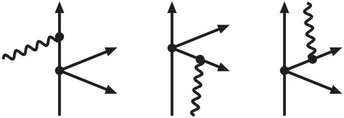


- Enhancement of $\sigma_{\rm tot}(s)$ by factor 1.5 - 1.8 through chiral corrections
- Suggestive explanation: $\pi^+\pi^- \to \pi^0\pi^0$ final state interaction $(1 + 0.20)^2$

$$\frac{1}{3}(a_0 - a_2) = \frac{3m_\pi}{32\pi f_\pi^2}\left[1 + \frac{m_\pi^2}{36\pi^2 f_\pi^2}\left(\bar{\ell}_1 + 2\bar{\ell}_2 - \frac{3\bar{\ell}_3}{8} + \frac{9\bar{\ell}_4}{2} + \frac{33}{8}\right)\right]$$

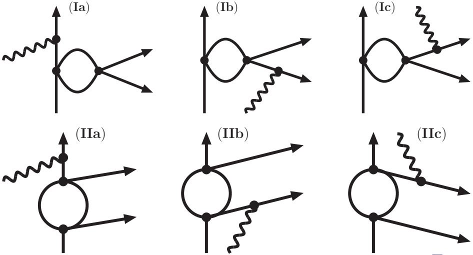
Charged pion-pair production

- 3-body process: $\pi^-(p_1) + \gamma(k,\epsilon) \to \pi^+(p_2) + \pi^-(q_1) + \pi^-(q_2)$
- Photon couples to all charged pions: $\to$ many more diagrams

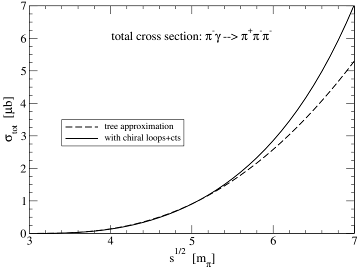


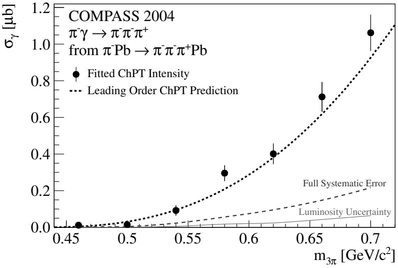
$$A_1^{(\text{tree})} = \frac{2s - 2m_\pi^2 - s_1 - s_2 + t_1 + t_2}{3m_\pi^2 - s - t_1 - t_2} + \frac{s - s_1 - s_2 + t_2}{t_1 - m_\pi^2}$$

$$A_2^{(\text{tree})} = \frac{2s - 2m_\pi^2 - s_1 - s_2 + t_1 + t_2}{3m_\pi^2 - s - t_1 - t_2} + \frac{s - s_1 - s_2 + t_1}{t_2 - m_\pi^2}$$



- Total cross section for $\pi^-\gamma \to \pi^+\pi^-\pi^-$



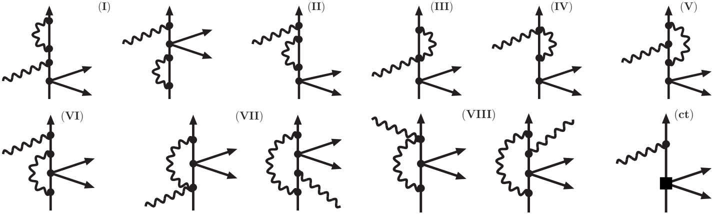


- $\sigma_{\text{tot}}(s)$ for $\sqrt{s} < 6m_\pi$ almost unchanged in comparison to tree approx.
- Suggestive explanation: $\pi^-\pi^- \to \pi^-\pi^-$ final state interaction $(1-0.02)^2$

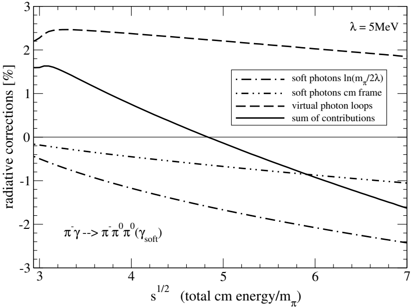
$$a_2 = -\frac{m_\pi}{16\pi f_\pi^2}\left[1 - \frac{m_\pi^2}{12\pi^2 f_\pi^2}\left(\bar{\ell}_1 + 2\bar{\ell}_2 - \frac{3\bar{\ell}_3}{8} - \frac{3\bar{\ell}_4}{2} + \frac{3}{8}\right)\right]$$

- Analysis of COMPASS data for $\sqrt{s} \leq 5m_\pi$ agrees with ChPT prediction
  First measurement of chiral dynamics in $\pi^-\gamma \to \pi^-\pi^-\pi^+$, PRL108, 192001 ('12)
- Agreement on level of full 5-dimensional phase space distribution

- Chiral $\pi^+\pi^- \to \pi^0\pi^0$ transition amplitude factors out of all photon loops



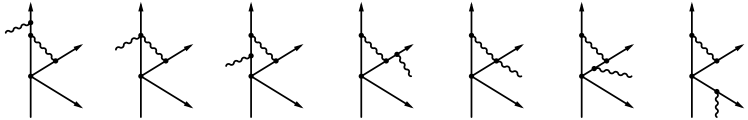
- Observe: Only "irreducible" photon-loop diagrams in 2nd row contribute



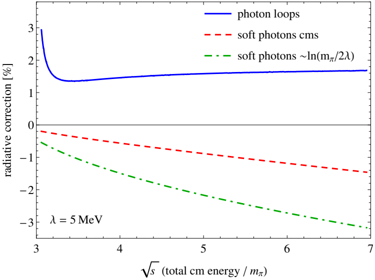
- Radiative correction to total cross section varies between $+2\%$ and -2%

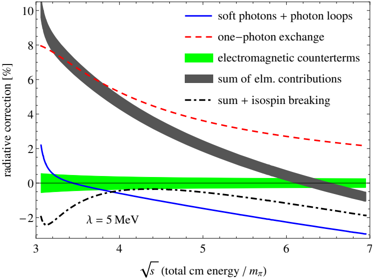
Radiative corrections to charged pion-pair production

- 42 irreducible photon-loop diagrams: virtual photon connects two differ. charged pions, all couplings of incoming photon [FeynCalc + LoopTools]



- Radiative corrections to total cross section $\sigma_{\rm tot}(\pi^-\gamma \to \pi^+\pi^-\pi^-)$





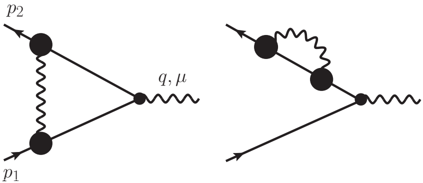
- Photon-loops almost constant, near threshold Coulomb singularity α/v
- Coulomb singularity causes kink in $\pi^+\pi^-$ and $\pi^-\pi^-$ mass spectra
- One-photon exchange is sizeable, compensated partly by leading isospin-breaking correction $\delta_{ib} = 2(m_{\pi^0}/m_\pi)^2 - 2 = -0.13$

Radiative corrections to magnetic moments of proton and neutron

- Measured values of proton/neutron magnetic moment extremely precise

$$\mu_p = 1 + \kappa_p = 2.7928473 \quad \mu_n = 0 + \kappa_n = -1.913042\,, \quad \text{in units of } \frac{e\hbar}{2M_p}$$

- Large anomalous magnetic moments κ_p, κ_n arise from strong interaction, but at given expt. precision electromagnetic effects play also a role: 10^{-3}
- Adapt Schwinger calc. for leptons $\delta\kappa_l = \frac{\alpha}{2\pi}$ to nucleons with structure $F_{1,2}$



- On-shell vector-vertex: $\gamma^\mu F_1^{(\gamma)}(t) + \frac{i}{2M}\sigma^{\mu\nu} q_\nu F_2^{(\gamma)}(t)$ with $t = (p_2 - p_1)^2 \leq 0$
- Project out $F_2^{(\gamma)}(t)$, careful limit $t \to 0$, Wick-rotation, angular integration

$$\int \frac{d^4 l}{(2\pi)^4 i} \frac{1}{(-l^2)} [\dots] = \frac{M^2}{4\pi^3} \int_0^\infty dx \int_{-1}^{1} dz\, x\sqrt{1-z^2}\, [\dots]$$

- Inclusion of wavefunction renormalization factor Z_2 from self-energy sub-diagram leads to infrared-finite and gauge-invariant result

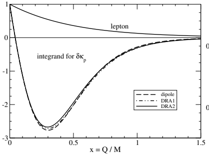
- Radiatively induced magnetic moment: $c = 1, 0$ and $\kappa = 1.793, -1.913$

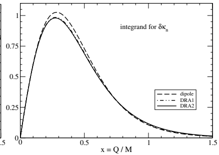
$$\delta\kappa = \frac{\alpha}{\pi}\int_0^\infty dx \left\{ \left[\left(\frac{2+4x^2+x^4}{\sqrt{4+x^2}} - 2x - x^3 \right) c + \left(\frac{x^2(10+3x^2)}{\sqrt{4+x^2}} - 4x - 3x^3 \right)\frac{\kappa}{4} \right] F_1^2(xM) \right.$$
$$+ \left[\left(\frac{x^2(7+2x^2)}{\sqrt{4+x^2}} - 3x - 2x^3 \right) c + \left(\frac{x^2(10+3x^2)}{\sqrt{4+x^2}} - 4x - 3x^3 \right)\frac{\kappa}{2} \right] F_1(xM)F_2(xM)$$
$$+ \left[\left(\frac{x^2}{\sqrt{4+x^2}}(16+x^2-x^4) - 8x - 3x^3 + x^5 \right)\frac{c}{8} \right.$$
$$\left. \left. + \left(\frac{x^2}{\sqrt{4+x^2}}(64+16x^2-x^4) - 32x - 18x^3 + x^5 \right)\frac{\kappa}{32} \right] F_2^2(xM) \right\}$$

- Numerical values of $\delta\kappa$ and corresponding integrands (without α/π)

form factor	dipole	DRA1	DRA2
$10^3 \cdot \delta\kappa_p$	-3.47	-3.49	-3.42
$10^3 \cdot \delta\kappa_n$	1.37	1.34	1.34

dispersion relation analyses





- Photon-loops with internal $\Delta(1232)$-isobars: Rarita-Schwinger formalism
- Convent. $\Delta N\gamma$-vertex + propagator: $\delta\kappa_p = -0.9\cdot 10^{-3}$, $\delta\kappa_n = 1.2\cdot 10^{-3}$
- Using spin-3/2 projected versions: $\delta\kappa_p = 0.0\cdot 10^{-3}$, $\delta\kappa_n = -0.8\cdot 10^{-3}$
- Estimate of genuine strong parts: $\kappa_p^{(strong)} = 1.797, \quad \kappa_n^{(strong)} = -1.915$