Light Mesons and Muon Radiative Decays and Photon Polarization Asymmetry

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Outlook

- Meson and Muon radiative polarized decays

$\pi^+ \to \nu\, \ell^+\, \gamma$ $K^+ \to \nu\, \ell^+\, \gamma$ $\mu^- \to \nu_\mu\, \overline{\nu}_e\, e^-\, \gamma$

- photon polarization asymmetry
- anomalous helicity-flip of final lepton
- tensorial couplings
- conclusions

Introduction

- Radiative decays of meson and leptons widely studied both experimental and theoretical
- excellent sources for precision tests of SM
- polarized decays analyzed only more recently

  pion muon

  (Trentadue-Verbeni ('00), Fischer et. al ('03), Sehgal-Schulz ('03))

- more detailed informations with respect to the unpolarized cases are available

- non vanishing rate for helicity-flip of electron when $m_e \longrightarrow 0$ manifestation of **axial anomaly**

  (Dolgov-Zakharov ('71))

- finiteness of polarized processes against infrared and collinear singularities take place with different mechanisms distinguish between **right- and left-handed** final leptons

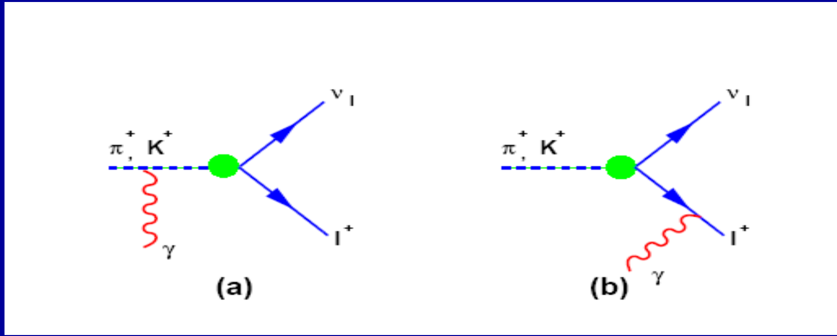
- polarized processes are more sensitive (with respect to unpolarized ones) to **New Physics** effects beyond the Standard Model

- we take into account also the **photon polarization** - not systematically analyzed before
- **photon polarization asymmetry** gives a direct misure of parity violation

$$M^{+}(p) \rightarrow \nu(p_\nu) + \ell^{+}(p_l, \lambda_l) + \gamma(k, \lambda_\gamma)$$

$$M = (K, \pi)$$

Inner Bremsstrahlung Ampl. →

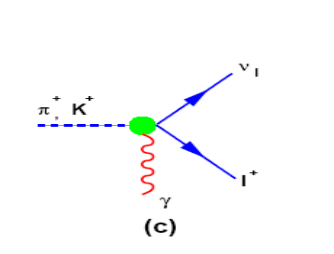


f_M → meson decay constant

$$\mathrm{M}_{IB}^{(\lambda_l,\lambda_\gamma)} = \frac{ieG_F}{\sqrt{2}} m_l f_M V_{uq}\ \epsilon^{\star}_{\mu}(k,\lambda_\gamma)\left[\bar{u}(p_\nu)\left(\frac{p^\mu}{(p\cdot k)} - \frac{\not k\gamma^\mu + 2p_l^\mu}{2\,(p_l\cdot k)}\right)(1+\gamma_5)\, v(p_l,\lambda_l)\right]$$

G_F → Fermi constant

Structure Dependent Ampl. →



independent gauge invariant contributions

$$\mathrm{M}_{SD}^{(\lambda_l,\lambda_\gamma)} = -\frac{ieG_F}{\sqrt{2}} V_{uq}\ \epsilon^{\star}_{\mu}(k,\lambda_\gamma)\left\{(p\cdot k)\,\frac{A}{m_M}\left(-\eta^{\mu\nu} + \frac{p^\mu k^\nu}{(p\cdot k)}\right) + i\epsilon^{\mu\nu\alpha\beta}\frac{V}{m_M}k_\alpha p_\beta\right\} \times \left[\bar{u}(p_\nu)\gamma_\nu\,(1-\gamma_5)\, v(p_l,\lambda_l)\right],$$

→ V and A Form Factors

$$\mathrm{V}^{\mu\nu}(p,k) = i\frac{V}{m_M}\epsilon^{\mu\nu\alpha\beta}k_\alpha p_\beta$$

$$\mathrm{A}^{\mu\nu}(p,k) = (p\cdot k)\frac{A}{m_M}\left(\eta^{\mu\nu} - \frac{p^\mu k^\nu}{(p\cdot k)}\right) - f_M\left(\eta^{\mu\nu} + \frac{p^\mu\,(p^\nu - k^\nu)}{(p\cdot k)}\right)$$

$$(\mathrm{V},\mathrm{A})^{\mu\nu}(p,k) \equiv \int d^4x e^{ikx}\langle 0|\ TV^\mu_{\rm em}(x)(V(0),A(0))^\nu\ |M^+(p)\rangle$$

polarized amplitude

$$x \equiv \frac{2p\cdot k}{m_M^2}, \quad y \equiv \frac{2p\cdot p_l}{m_M^2}, \quad z \equiv \frac{2p_l\cdot k}{m_M^2} = y - 1 + x - r_l$$

$\lambda = +1$ right-handed = R

$\lambda = -1$ left-handed = L

<u>In the center of mass frame of final leptons</u>

$$\begin{aligned}
\mathrm{M}_{IB}^{(\lambda_l,\lambda_\gamma)} &= eG_F m_l f_M V_{uq}\, \frac{2}{z} \left\{ \delta_{\lambda_l,-1} \left(\delta_{\lambda_\gamma,-1}\, \hat{E}_\gamma + \hat{E}_\nu \right) R_+ \sin\theta \right. \\
&+ \left. \delta_{\lambda_l,+1}\, \delta_{\lambda_\gamma,-1}\, \hat{E}_\gamma R_- \left(1-\cos\theta\right) \right\} e^{i\lambda_\gamma\varphi}
\end{aligned}$$

$$\begin{aligned}
\mathrm{M}_{SD\pm}^{(\lambda_l,\lambda_\gamma)} &= eG_F m_M^2 V_{uq}\, \frac{(V\pm A)}{2}\, \delta_{\lambda_\gamma,\pm1}\; x \left\{ \mp\, \delta_{\lambda_l,-1}\; R_- \sin\theta \right. \\
&\pm \left. \delta_{\lambda_l,+1} R_+ \left(\cos\theta \pm 1\right) \right\}\, e^{i\lambda_\gamma\varphi} \, ,
\end{aligned}$$

$V + A$ → **R-photons**

$V - A$ → **L-photons**

ϑ angle between photon and lepton momenta

IB is a mixture of left- and right-handed photon polarizations

$$\begin{aligned}
\hat{E}_\gamma &= \frac{x}{2\sqrt{1-x}}, \quad \hat{E}_\nu = \frac{1-x-r_l}{2\sqrt{1-x}}, \quad \hat{E}_l = \frac{1-x+r_l}{2\sqrt{1-x}} \\
\cos\theta &= \frac{(x-2)(1-x+r_l)+2y(1-x)}{x(1-r_l-x)}
\end{aligned}$$

$$R_+ = \sqrt{1-r_l-x}, \quad R_- = \sqrt{r_l\frac{1-r_l-x}{1-x}}$$

Dalitz plot for photon polarization

in the meson rest frame $x = \frac{2E_\gamma}{m_M}$ $y = \frac{2E_l}{m_M}$ $\lambda \approx \frac{E_l}{m_M}(1 - \cos(\vartheta))$ $\lambda = z/x$

$$\frac{d^2\Gamma^{(\lambda_\gamma)}}{dx\, d\lambda} = \frac{m_{\mathrm{M}}}{256\pi^3} \sum_{\lambda_l=\pm1} |\mathrm{M}^{(\lambda_l,\lambda_\gamma)}|^2 = \rho^{(\lambda_\gamma)}(x,\lambda)$$

L-
$$\rho^{(-1)}(x,\lambda) = A_{IB}\, f_{IB}^{\mathrm{L}}(x,\lambda) + A_{SD}\,\frac{1}{2}(V-A)^2 f_{SD}^{\mathrm{L}}(x,\lambda) + A_{INT}(V-A) f_{INT}^{\mathrm{L}}(x,\lambda)$$

R-
$$\rho^{(+1)}(x,\lambda) = A_{IB}\, f_{IB}^{\mathrm{R}}(x,\lambda) + A_{SD}\,\frac{1}{2}(V+A)^2 f_{SD}^{\mathrm{R}}(x,\lambda) + A_{INT}(V+A) f_{INT}^{\mathrm{R}}(x,\lambda),$$

$$A_{IB} = 2\, r_l \left(\frac{f_M}{m_M}\right)^2 A_{SD}, \quad A_{INT} = 2\, r_l\, \frac{f_M}{m_M}\, A_{SD}$$

$$A_{SD} = \frac{\alpha}{32\pi^2}\, G_F^2\, m_M^5\, |V_{uq}|^2\,.$$

- IB dominates in the soft photon region $x \to 0$
- hard photons accompanied by soft energy positrons are mainly Left-handed polarized
- in the $x \to 0$ limit, L and R-handed distributions tend to the same value → photon-spin decoupling property
- all these behaviours are a consequence of angular momentum conservation

$$
\begin{aligned}
f_{IB}^{\mathrm{L}}(x,\lambda) &= \frac{1-\lambda}{x\lambda}\left(1+r_l\,(x-1)-\frac{r_l}{\lambda}\,(1+x-r_l)\right) \\
f_{IB}^{\mathrm{R}}(x,\lambda) &= \frac{1-\lambda}{x\lambda}\left(x-1+\frac{r_l}{\lambda}\right)(x-1+r_l) \\
f_{SD}^{\mathrm{R}}(x,\lambda) &= x^2\lambda\left((1-x)\,(x\lambda+r_l)-r_l\right) \\
f_{SD}^{\mathrm{L}}(x,\lambda) &= x^2\,(1-\lambda)\left((x-1)\,(r_l+x\,(\lambda-1))+r_l\right) \\
f_{INT}^{\mathrm{R}}(x,\lambda) &= \frac{1-\lambda}{\lambda}\left((x-1)\,(x\lambda+r_l)+r_l\right) \\
f_{INT}^{\mathrm{L}}(x,\lambda) &= \frac{1-\lambda}{\lambda}\left(x^2+(1-x)\,(x\lambda+r_l)-r_l\right)\,.
\end{aligned}
$$

radiative pion decay

- the amplitude contains only **two free parameters V and A** form factors
- form factors contains the information about hadronic structure
- in general are not constant over all phase space
- evaluated in Chiral-perturbation theory at next-to-leading order momentum expansion. $O(p^6)$
- ChPt shows a mild dependence on momenta (Bijnens and Talavera (1997))
- V can be extracted from $\pi \to \gamma\gamma$ decay by using PCAC

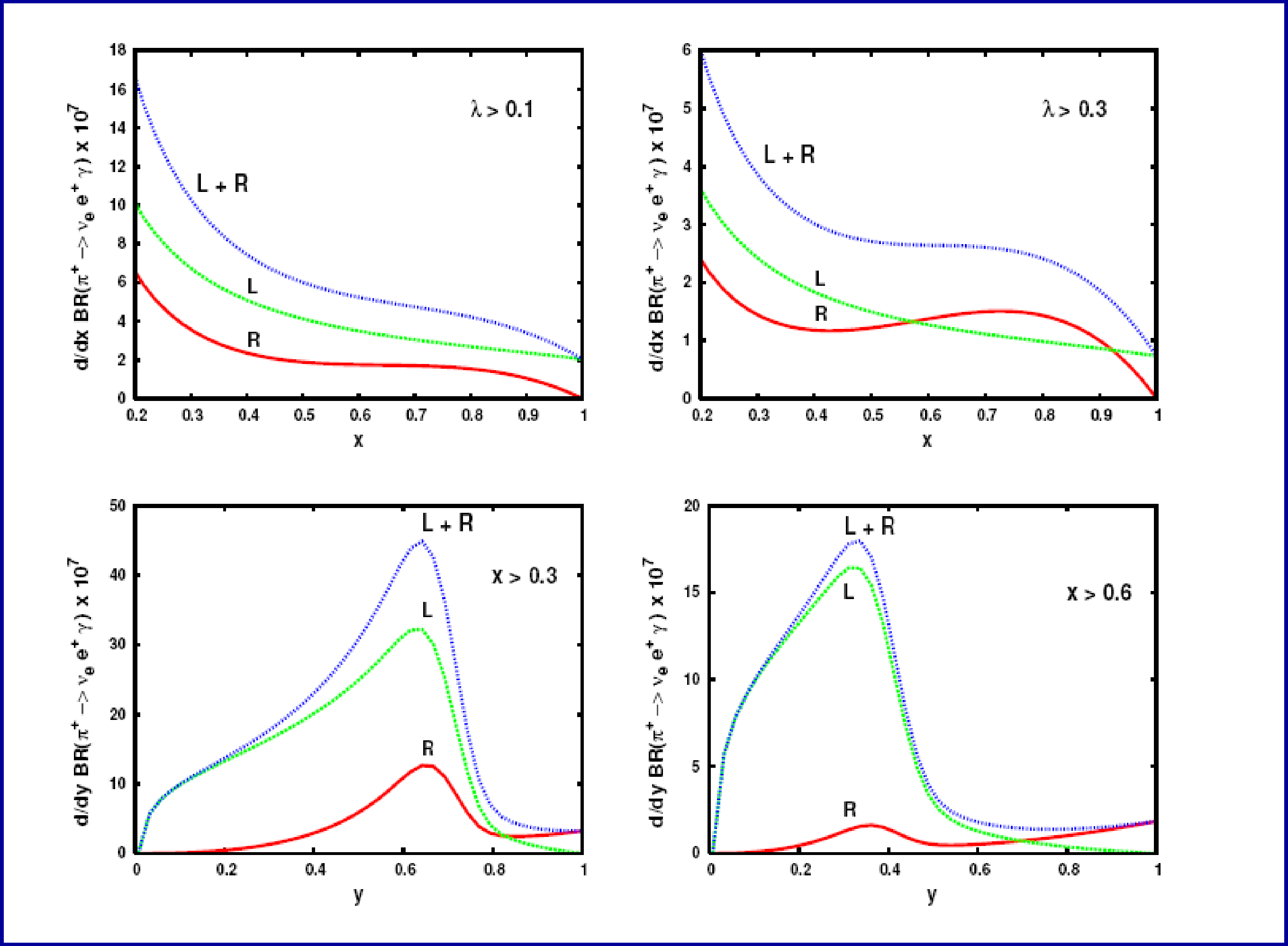
$$|V| = \frac{1}{\alpha}\sqrt{\frac{2\Gamma(\pi^0 \to \gamma\gamma)}{\pi\, m_{\pi^0}}} = 0.0259 \pm 0.0005$$

- the ratio $\gamma = V/A$ is measured from e channel. muon channel is not sensitive to form factors
- the most recent measurements of γ has been performed by PIBETA collaboration at PSI (2003)
- the preliminary results of PIBETA exp. indicate a deficit of events in $\pi^+ \to \nu e^+ \gamma$
- an analogous effect first observed in (´91) at ISTRA facility with pion decays in flight
- central value of best CVC fit $\gamma = 0.443 \pm 0.015$

$$\pi^+ \longrightarrow \nu_e \quad e^+ \quad \gamma$$

photon energy distribution

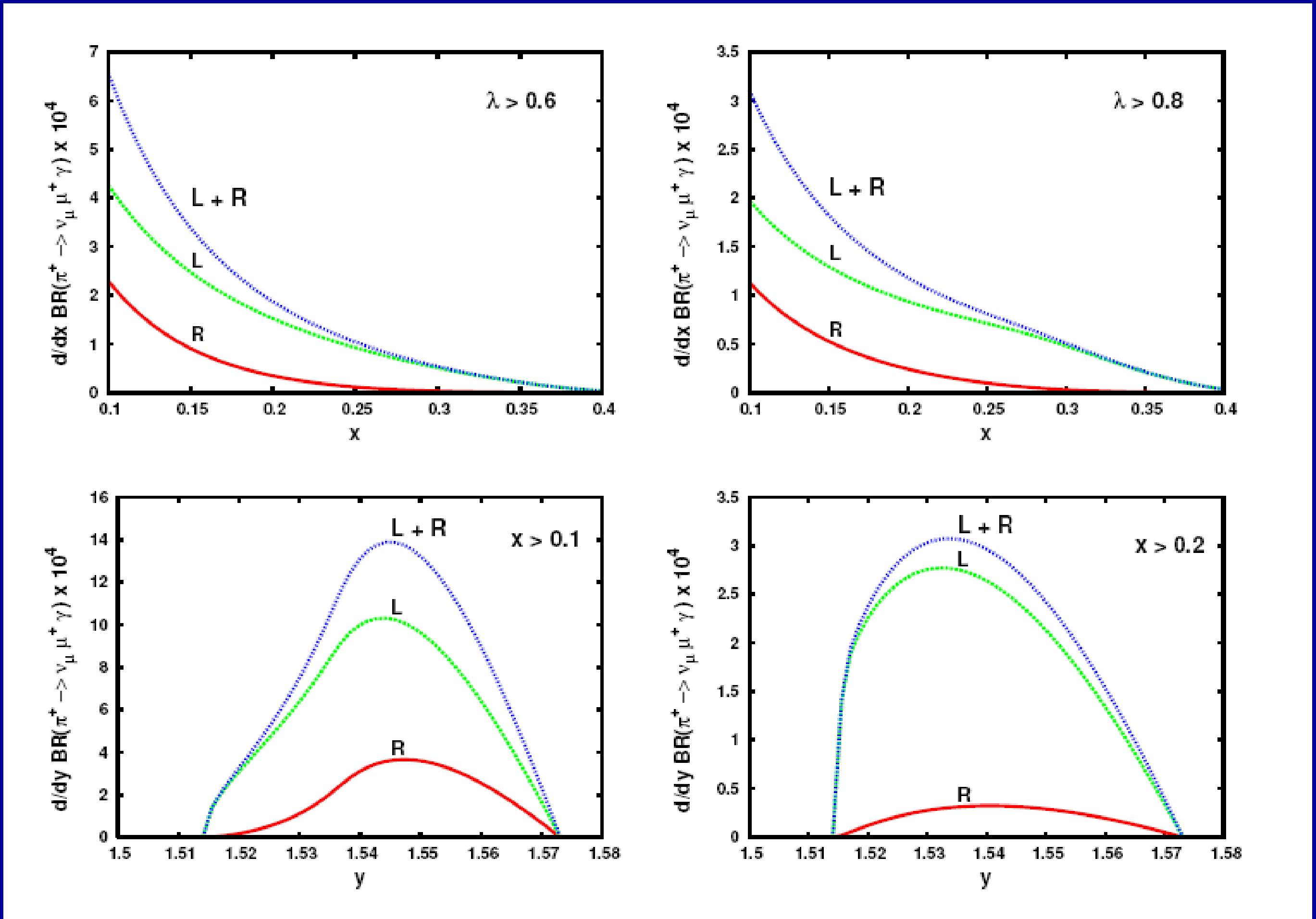
positron energy distribution



$$\pi^+ \longrightarrow \nu_\mu \ \mu^+ \ \gamma$$

photon energy distribution

muon(+) energy distribution



photon polarization asymmetry

$$\frac{\mathrm{dA}_\gamma}{\mathrm{d}\xi} \equiv \frac{\mathrm{d}_\xi(\mathrm{BR_L}) - \mathrm{d}_\xi(\mathrm{BR_R})}{\mathrm{d}_\xi(\mathrm{BR_L}) + \mathrm{d}_\xi(\mathrm{BR_R})}$$

$$\mathrm{d}_\xi(\mathrm{BR_{L,R}}) \equiv \frac{\mathrm{d\,BR_{L,R}}}{\mathrm{d}\xi}$$

- finite quantity, free from infrared divergencies

$$\lim_{x\to 0}\{\rho_\mathrm{L}(x,y) - \rho_\mathrm{R}(x,y)\} \rightarrow \mathcal{O}(x)$$

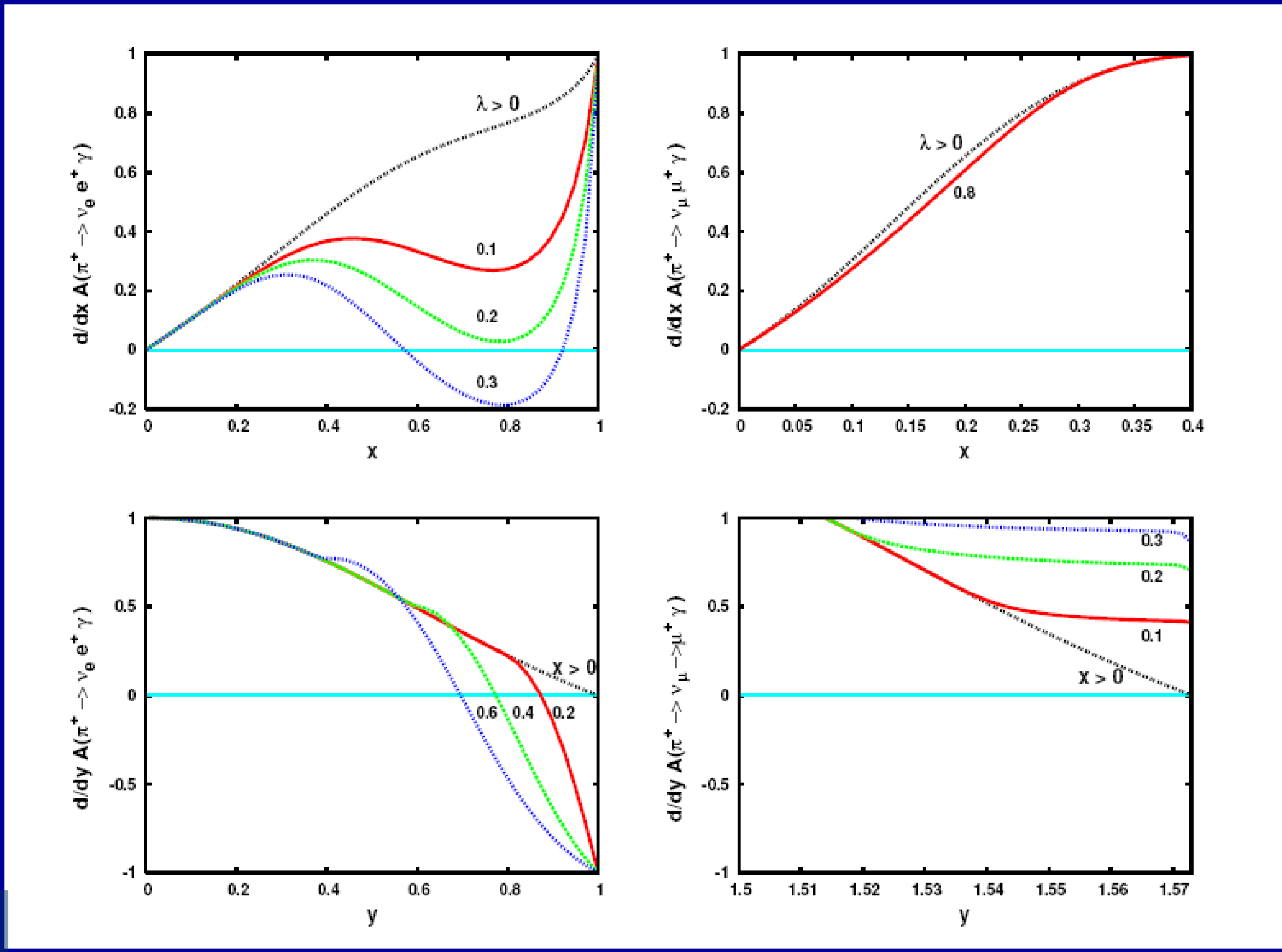
$$\lim_{x\to 0}\{\rho_\mathrm{L}(x,y) + \rho_\mathrm{R}(x,y)\} \rightarrow \log(x)$$

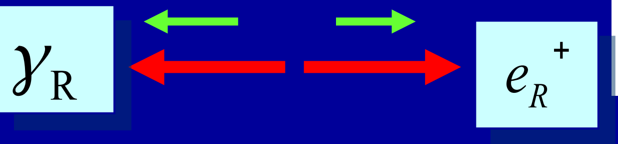
- very sensitive to hadronic form factors V and A
- providing a direct measure of parity violation

e^+ μ^+

photon energy distribution

lepton energy distribution





at large x and y regions SD ampl. dominates → e_R^+

and angular momentum conservation forces → γ_R

radiative Kaon decays

- most recent measurements

$$|V+A| = 0.165 \pm 0.007 \pm 0.011$$
$$-0.24 < V - A < 0.04 \text{ at } 90\% \text{ C.L.}$$

(E787 coll. (2001))

- almost 2 sigma deviation with respect to prediction in ChPT at LO
- ChPT at LO starts at $O(p^4)$ and predicts constant form factors
- momentum dependence starts at NLO in ChPT $O(p^6)$
- it is expected to be sizeable with respect to pion case about 10-20 % with resp. to LO (Geng, Ho, Wu (2004))
- momentum dependence is more sizeable in V than in A

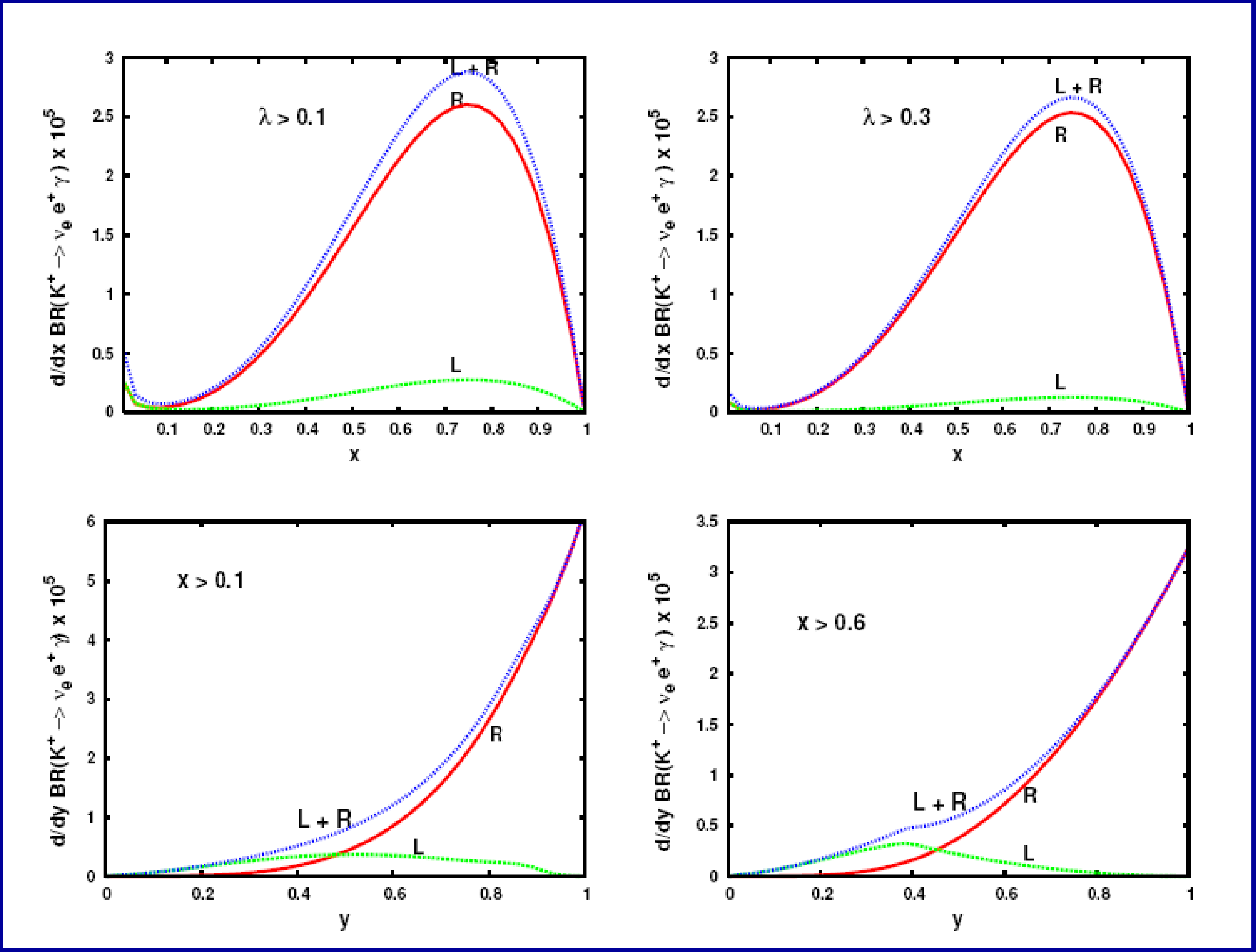
$$V + A = -0.137, \qquad V - A = -0.052$$

$K^+ \longrightarrow \nu_e \; e^+ \; \gamma$

we use results of one-loop ChPT

photon energy distribution

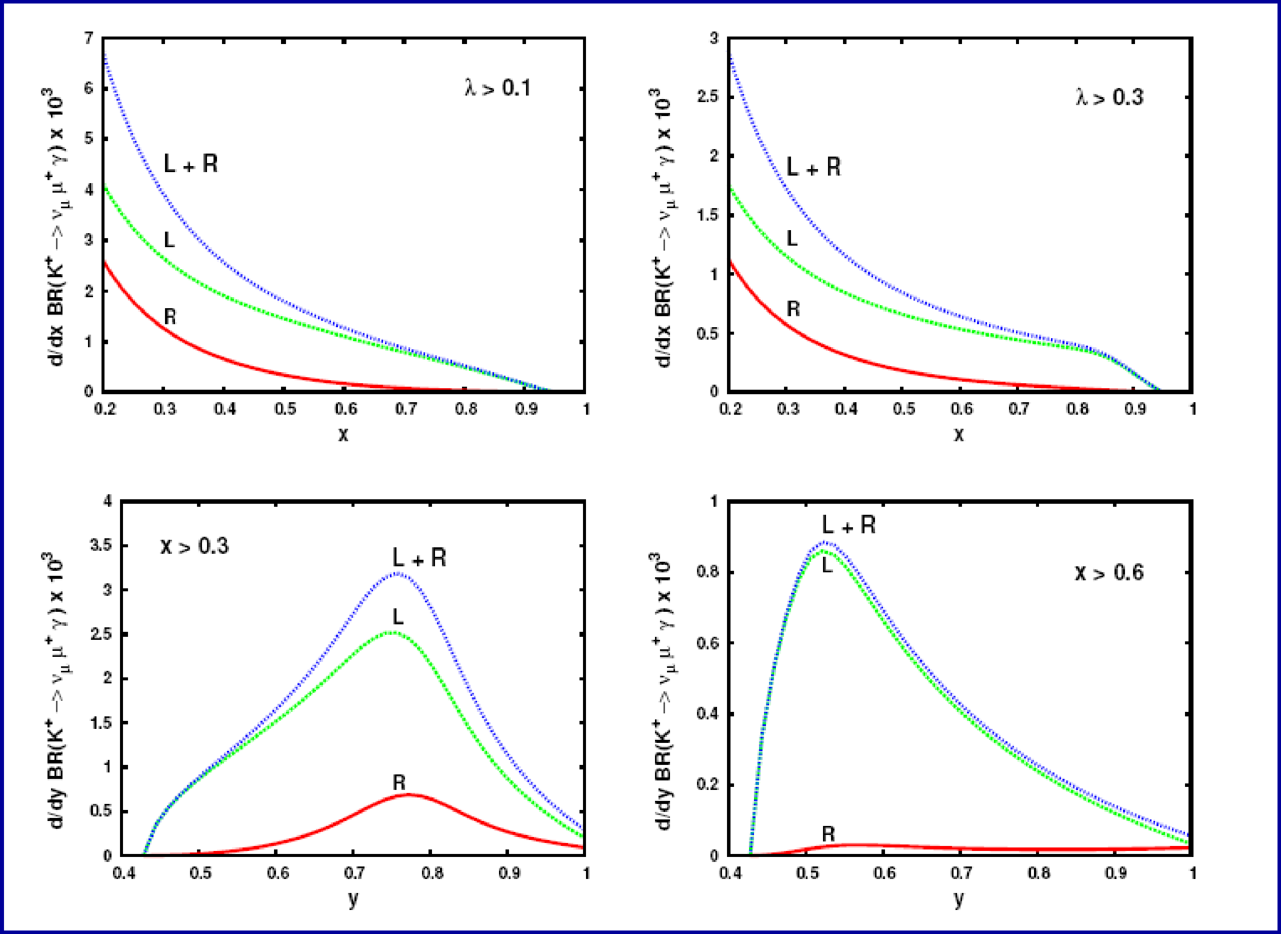
positron energy distribution



hard photons x > 0.1 are mainly Right-handed polarized

this effect is mainly due to SD terms

$K^+ \to \nu_\mu \; \mu^+ \; \gamma$



hard photons x > 0.1 are mainly Left-handed polarized

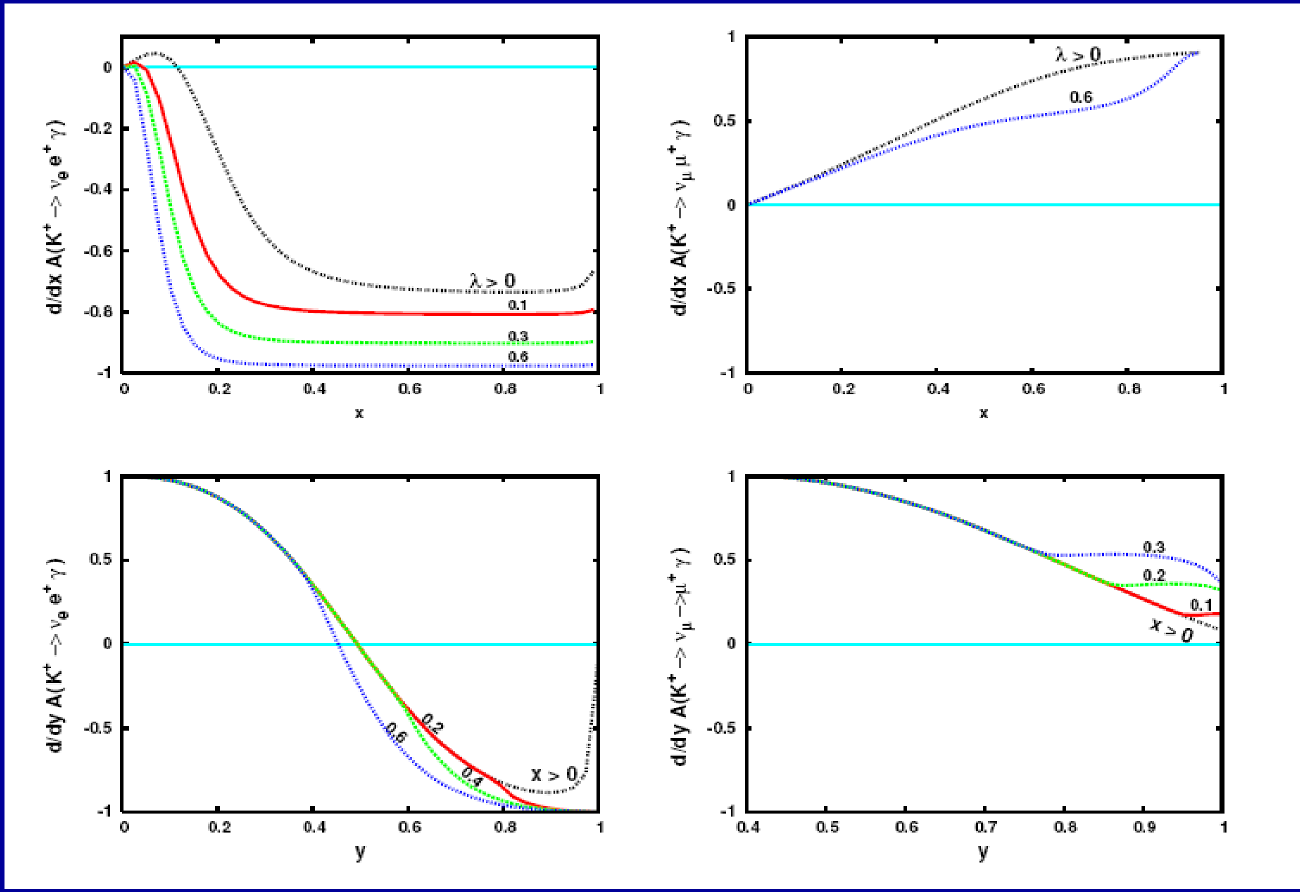
Effect mainly due to IB term

photon polarization asymmetry for Kaon decay

e^+ μ^+

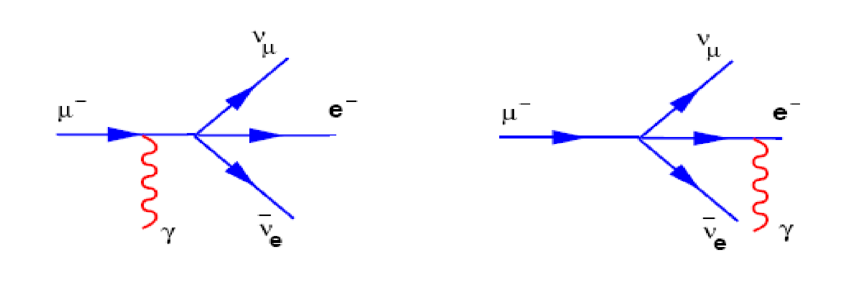
photon energy distribution

lepton energy distribution



Radiative muon decay

unpolarized
Kinoshita-Sirlin (´59)
Eckstein-Pratt (´59)



polarized in leptons
Fischer et al. (´03)
Sehgal-Schulz ('04)

Factorization after Fierz re-arrangement

$$|M^{(\lambda_\gamma,\lambda_e)}|^2 = \frac{G_F^2}{2}\left[M_\alpha^{(\lambda_\gamma,\lambda_e)\dagger}\, M_\beta^{(\lambda_\gamma,\lambda_e)}\right]\left[N^{\alpha\dagger}\, N^\beta\right]$$

charged lept.

neutrinos

$$x = \frac{2E_\gamma}{m_\mu}, \qquad y = \frac{2E_e}{m_\mu}, \qquad z = \frac{x}{2}\,(y - \mathrm{A_e}\,\cos\theta)$$

$$\mathrm{A_e} \equiv \sqrt{y^2 - 4r}$$

$$\frac{1}{\Gamma_0}\frac{d\Gamma^{(\lambda_\gamma\,,\,\lambda_e)}}{dx\,dy\,dz} = -\frac{\alpha}{2\pi}\left\{\frac{M_\alpha^{(\lambda_\gamma,\lambda_e)\dagger}M_\beta^{(\lambda_\gamma,\lambda_e)}\;N^{\alpha\beta}}{4\,m_\mu^2}\right\}$$

reduced phase space

$$-1 < \cos(\theta) < 1$$

$$0 \leq x \leq 2\left(\frac{1+r-y}{2-y+\mathrm{A_e}}\right)$$

$$2\sqrt{r} \leq y \leq 1+r$$

$$\frac{1}{\Gamma_0}\frac{d\Gamma^{(\lambda_\gamma,\lambda_e)}}{dx\,dy\,d\cos\theta} = \frac{\alpha}{8\pi}\,\frac{A_e}{x\,z^2}\left[g_0 + \lambda_\gamma\,\bar{g}_0 + \lambda_e\,(g_1 + \lambda_\gamma\,\bar{g}_1)\right]$$

retaining only the leading terms in m_e and x_0

integrating over the reduced phase space

$$\begin{aligned}
\frac{1}{\Gamma_0}\frac{d\Gamma^{(R,L)}}{dy} &= \frac{\alpha}{\pi}\,y^2\Big\{\Big[\log(x_0)-\log(1-y)\Big]\,(3-2\,y)\,(2+\log(r)-2\,\log(y)) \\
&+ \frac{1}{18}\,(1-y)\Big(57+36\,\log(r)+28\,y+y^2+4\,y^3-72\,\log(y)\Big)\Big\} \\
\frac{1}{\Gamma_0}\frac{d\Gamma^{(R,R)}}{dy} &= 0 \\
\frac{1}{\Gamma_0}\frac{d\Gamma^{(L,L)}}{dy} &= \frac{\alpha}{\pi}\,\Big\{\Big[\log(x_0)-\log(1-y)\Big]y^2\,(3-2\,y)\,(2+\log(r)-2\,\log(y)) \\
&- \frac{1}{12}\,(y-1)^2\,\Big(10+96\,y+5\,y^2+2\,\log(r)\,(5+22\,y) \\
&- 4\,(5+22\,y)\,\log(y)\Big)\Big\} \\
\frac{1}{\Gamma_0}\frac{d\Gamma^{(L,R)}}{dy} &= \frac{\alpha}{6\pi}\,(1-y)^2\,(5-2y)\,.
\end{aligned}$$

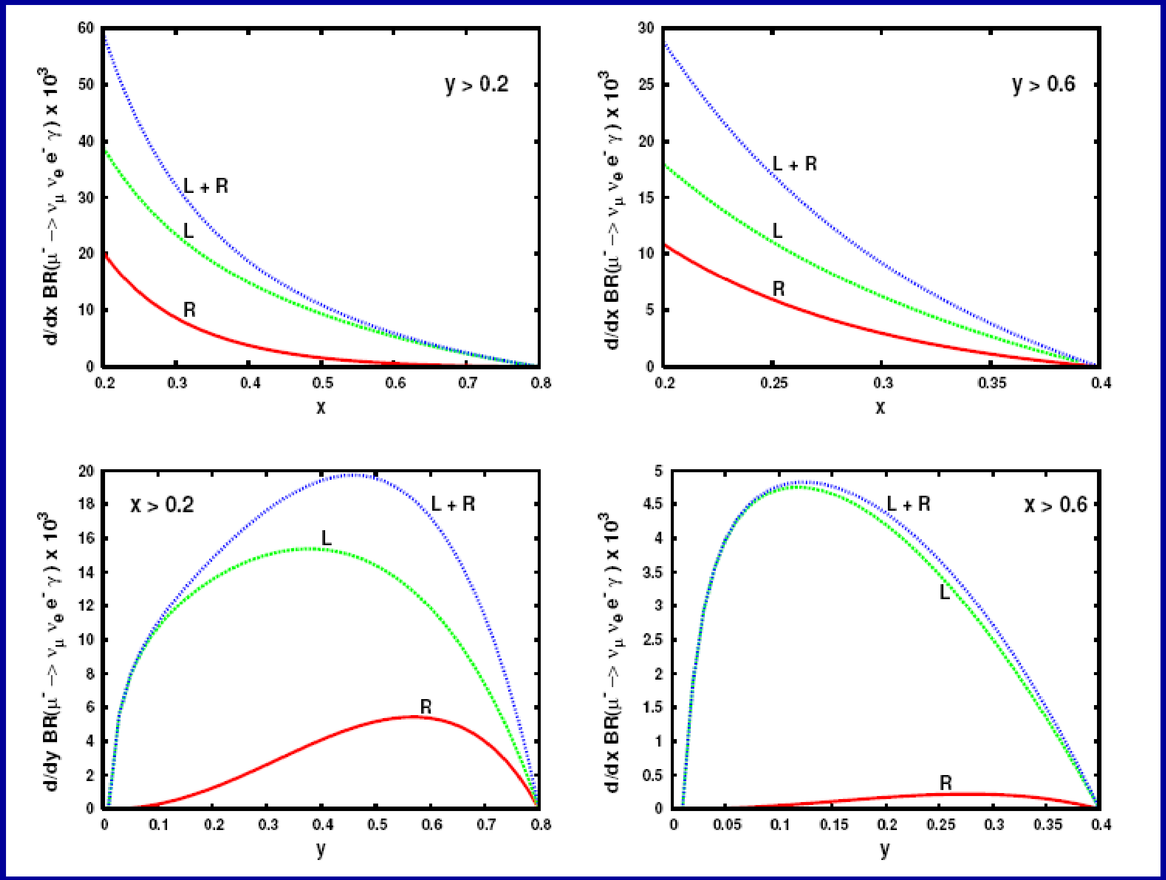
→ R-photon R-electron

→ L-photon R-electron

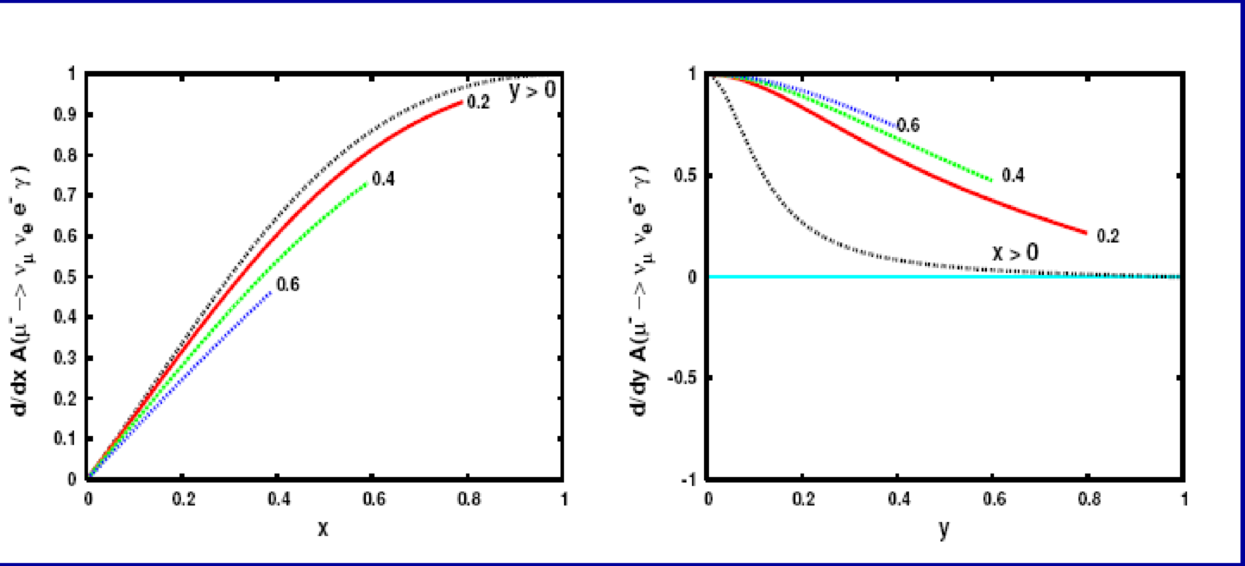
$$\mu^- \to \nu_\mu \, \bar{\nu}_e \, e^- \, \gamma$$

photon energy distribution

electron energy distribution



photon polarization asymmetry for muon radiative decay



The anomalous helicity flip contribution

- **naive prediction of massless QED is that helicity flip contribution vanishes at any order in perturbation theory**

- **Lee and Nauenberg ('64) pointed out that there will be a non-zero helicity-flip contribution from collinear photon emission surviving the limit** $m_e \to 0$

- **this phenomena happens also in meson and muon radiative decays (Trentadue and Verbeni ('03), Fischer et al. ('02), Sehgal and Schulz ('03))**

- in the radiative scattering of electrons from Coulomb field the probability of helicity flip in the massless limit does not vanish

$$\frac{d\sigma}{d\theta^2} \sim \frac{\left(\frac{m_e}{E_e}\right)^2}{\left(\left(\frac{m_e}{E_e}\right)^2 + \theta^2\right)^2}$$

- in massless electron theory, positron will be emitted left-handed in IB contribution to meson decay and analogously for the electron in muon decay

- **finite right-handed positron/electron contribution in the massless limit**

- **axial anomaly can be traced to the existence of an anomalous helicity-flip contribution to the absorbitive part of VVA triangle diagram in massless QED (Dolgov-Zakharov ('71))**

Right-handed final lepton

L-photon → R-positron

meson decay

$$\lim_{r_l \to 0} \frac{1}{\Gamma_0} \frac{d\Gamma^{(\mathrm{L,R})}_{IB}}{dy} = \frac{\alpha}{2\pi}\left(1-y\right)$$

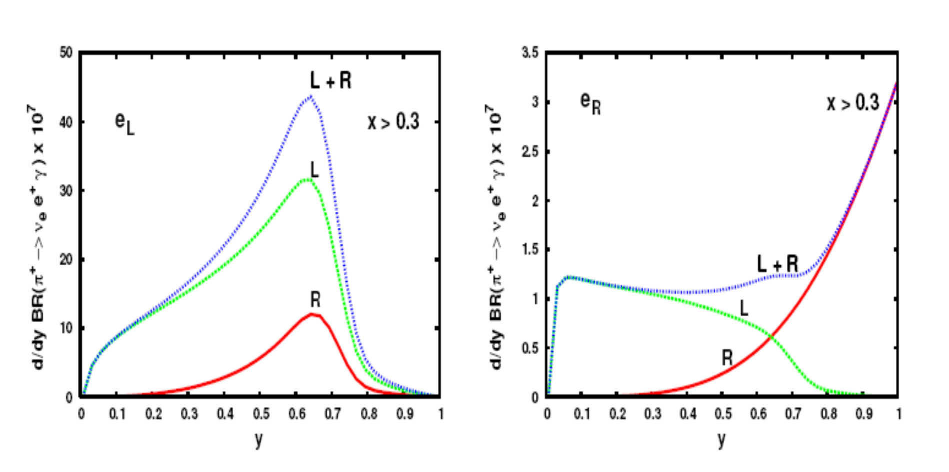
L-photon → R-electron

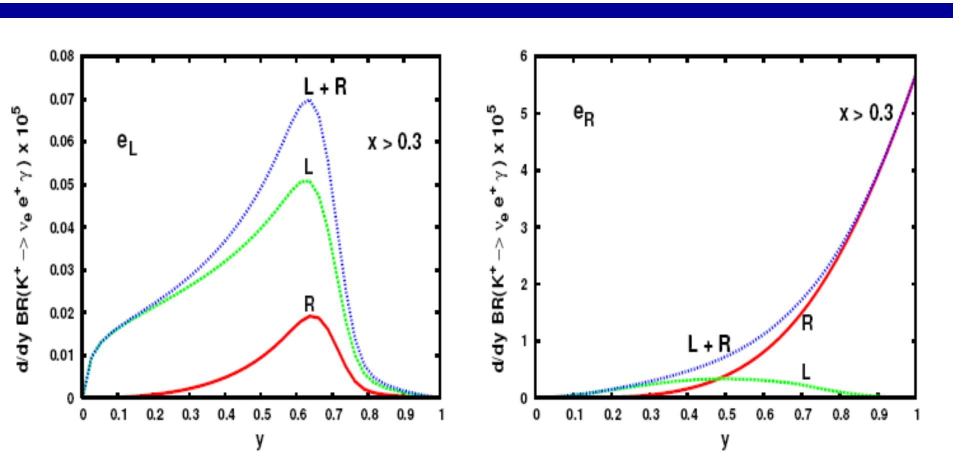
muon decay

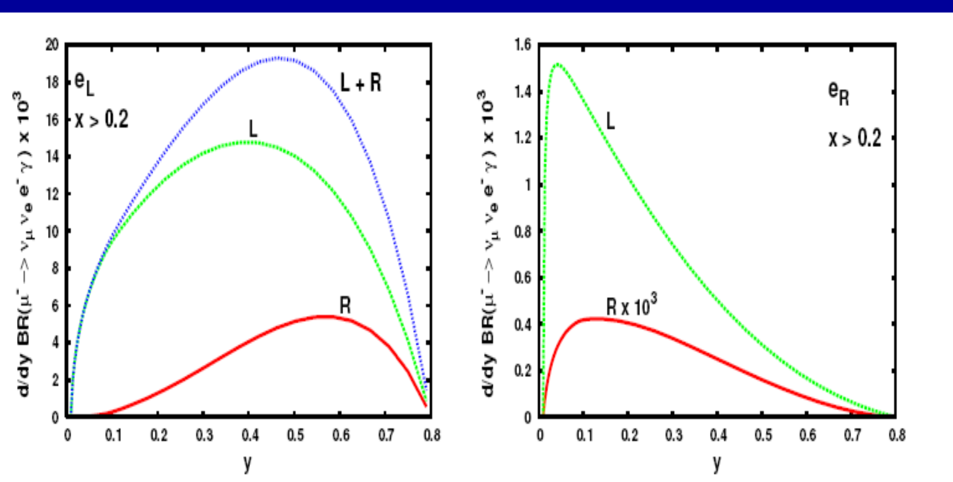
$$\lim_{r_l \to 0} \frac{1}{\Gamma_0} \frac{d\Gamma^{(L,R)}}{dy} = \frac{\alpha}{6\pi}\left(1-y\right)^2\left(5-2y\right)$$

1- R-handed photon contribution vanishes

2- L-handed photon contribution is finite
from infrared and collinear divergencies







pion → L-e >> R-e

SD terms gives main contribution to R-el polar. in large y-regions

Kaon → R-e >> L-e

muon → L-el >> R-el

Cancellation of mass singularities

- peculiar cancellation pattern of mass singularities appear in polarized processes different from unpolarized case

- mass singularities are of 2 types:
  infrared → $E_\gamma \longrightarrow 0$
  collinear → $\vartheta \longrightarrow 0$

$$q^2 = (p+k)^2 = 2\, p_0\, E_\gamma (1 - \cos\theta) \rightarrow\ 0$$

- Bloch-Nordsiek theorem assures cancel. of infrared singularities in inclusive processes (tree + loops)

- keeping the fermion mass finite does not give rise to any collinear singularity

- cancellation of collinear divergencies in inclusive unpolarized process are governed by the Kinoshita-Lee-Nauenberg theorem

- different polarization amplitudes do represent independent observables.
- right-handed and left-handed have to be separately finite

meson

$$\lim_{r_l \to 0} \lim_{y \to 1} \frac{1}{\Gamma_0} \frac{d\Gamma_{IB}^{(\mathrm{L,R})}}{dy} = \frac{\alpha}{2\pi}\Big(1-y\Big) = 0$$

muon

$$\lim_{r_l \to 0} \lim_{y \to 1} \frac{1}{\Gamma_0} \frac{d\Gamma^{(L,R)}}{dy} = \frac{\alpha}{6\pi}(1-y)^2(5-2y) = 0$$

- the right-handed contribution is finite by itself, free from infrared $y \to 1$ and collinear $r_l \to 1$ limits

$$\frac{1}{\Gamma_0}\Big[\frac{d\Gamma_{IB}^{(\mathrm{L,L})}}{dy} + \frac{d\Gamma_{IB}^{(\mathrm{R,L})}}{dy}\Big] = \frac{\alpha}{2\pi}\,\frac{1}{y-1}\Big[\Big(1 + y - \hat{L}_1 - \hat{L}_2\Big) + \Big(y\,(y+1) - \hat{L}_1\,y^2 + \hat{L}_2\,(1-2\,y)\Big)\Big]$$

- it is divergent both in the infrared and collinear limit

$$\hat{L}_1 \approx \log\frac{m_l}{m_M}$$

- as for the unpolarized case for the left-handed lepton contributions one needs to consider the additional virtual contribution to cancel infrared singularities

- the cancellation of divergencies occur in the total inclusive decay rate, when we add all the first order contributions, i.e. real and virtual photon emission

IB contribution including the virtual one

$$\frac{1}{\Gamma_0}\frac{d\Gamma}{dy} = \delta(1-y) + \frac{\alpha}{\pi}(L-1)P^{(1)}(y) + \frac{\alpha}{\pi}R_l(y)]$$

$$P^{(1)}(y) = \frac{1+y^2}{1-y} - \delta(1-y)\int_0^1 dz\frac{1+z^2}{1-z}$$

Gribov-Lipatov Altarelli-Parisi kernel

$$R_l(y) = 1 - y - \frac{1}{2}(1-y)\log(1-y) + \frac{1+y^2}{1-y}\log\ y$$

inclusive width gives a finite result

$$\frac{\Gamma}{\Gamma_0} = 1 + \frac{\alpha}{\pi}[\frac{15}{8} - \frac{\pi^2}{3}]$$

Tensorial couplings

- **PIBETA collaboration at PSI facility ('03) has recently performed a precise measurement of** $\pi^+ \longrightarrow \nu_e e^+ \gamma$
- **more than 40,000 events have been collected**
- **a significant discrepancy about** 8σ **between SM predictions and measured BR has been reported**
- **large number of missing events in the kinematical region of high-energy photons and low-energy positron has been observed**
- **a less pronounced discrepancy was already reported at ISTRA facility (´90) within the same kin. region**

- this result can be explained as the effect of **a centi-weak tensorial interaction** beyond V-A theory

Poblaguev ('90)

$$H_{eff}^{\Delta S=0} = \frac{f_T G_F}{2\sqrt{2}} V_{ud} \left[\bar{u}\sigma_{\mu\nu}(1-\gamma_5)d\right] \left[\bar{e}\sigma_{\mu\nu}(1-\gamma_5)\nu_e\right] + \text{h.c.}$$

- where $\sigma_{\mu\nu} = 1/2[\gamma_\mu, \gamma_\nu]$ and f_T is a dimensionless coupling

- **destructive interference with new Tens. amplitude**

$$M_T = i\frac{eG_F}{\sqrt{2}} V_{ud}\, F_T \epsilon^{\mu\star}\, q^\nu \left[\bar{e}\sigma_{\mu\nu}(1-\gamma_5)\nu_e\right]$$

$$F_T \approx 5\times 10^{-3}$$

low-energy theorems +PCAC

$$F_T^0 = \frac{2}{3}\frac{\chi\langle\mu\rangle}{f_\pi} f_T^0$$

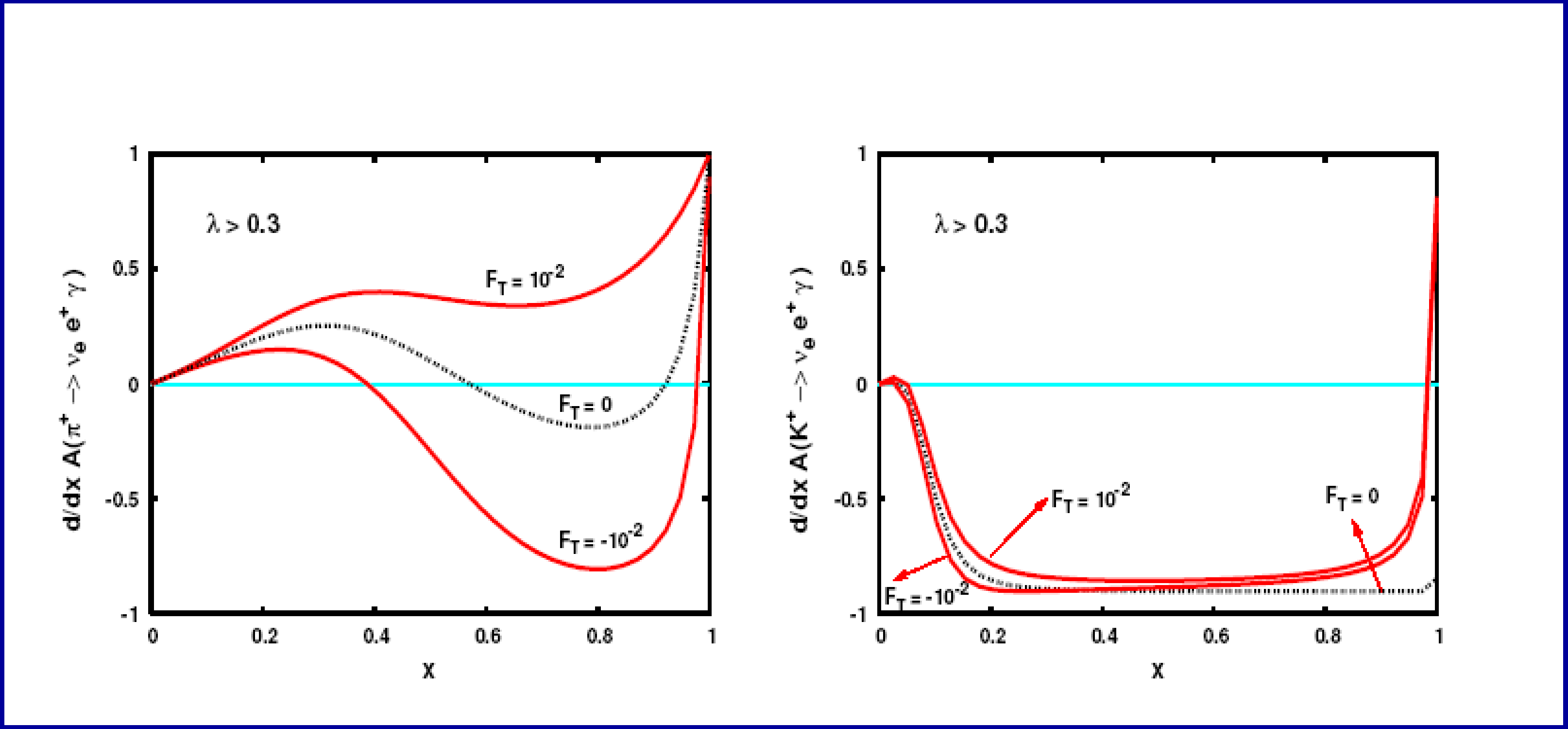
$$\langle 0|\bar{q}\sigma_{\mu\nu}q|\epsilon(k)\rangle = e_q\chi\,\langle 0|\bar{q}q|0\rangle\, F_{\mu\nu}$$

- if confirmed this anomaly will be a spectacular signal of new physics.
- SM predicts a coupling $f_T \approx 10^{-8}$
- SUSY models $f_T\,(\mathrm{SUSY}) \leq 10^{-4}$ (Belyaev –Kogan '92)
- controversial arguments: Voloshin ('91) showed that the tensorial operator can mix with scalar operator under QED corrections
- due to the strong bounds on couplings of scalar operators one gets

$$f_T\,(\mathrm{scalar}) \leq 10^{-4}$$

- however there are ways to relax such bound
- fine tuning with other operators (Herczeg '94, Chizov '93)
- analogous effect is predicted in radiative Kaon decay (Gabrielli '92)

tensorial contribution to photon polarization asymmetry



$\pi^+ \rightarrow \nu\, e^+\, \gamma$

$K^+ \rightarrow \nu\ \ e^+\ \ \gamma$

rad. pion decay is very sensitive to tensorial couplings of centiweak strenght.

Conclusions

- we analyzed polarized distributions in radiative meson and muon decays
- the definition of photon-polarization-asymmetry has been introduced
- allowing a new approach to investigate interaction dynamics via a finite and universal quantity
- directly connected to parity violation.
- In the pion case the production of hard photons in association with soft positron are mainly left-handed polarized
- on the contrary in Kaon case when energy cuts are imposed

  $E_\gamma \gtrsim 25$ MeV and $E_{e^+} \gtrsim 120$ MeV

  both positron and photon are mainly right-handed polarized

- regarding the meson decay in muon channel, photon is mainly left-handed polarized,
- the same behavior holds for muon decay.
- Mechanisms of cancellations of mass singularities have been analyzed for polarized processes :
- right-handed letpon contributions are finite
- while left-handed ones are only finite for inclusive processes, i.e. virtual + radiative photons.
- Finally we propose a possible test to solve the controversial issue of tensorial coupling in rad. pion decay, by using photon polarization asymmetry