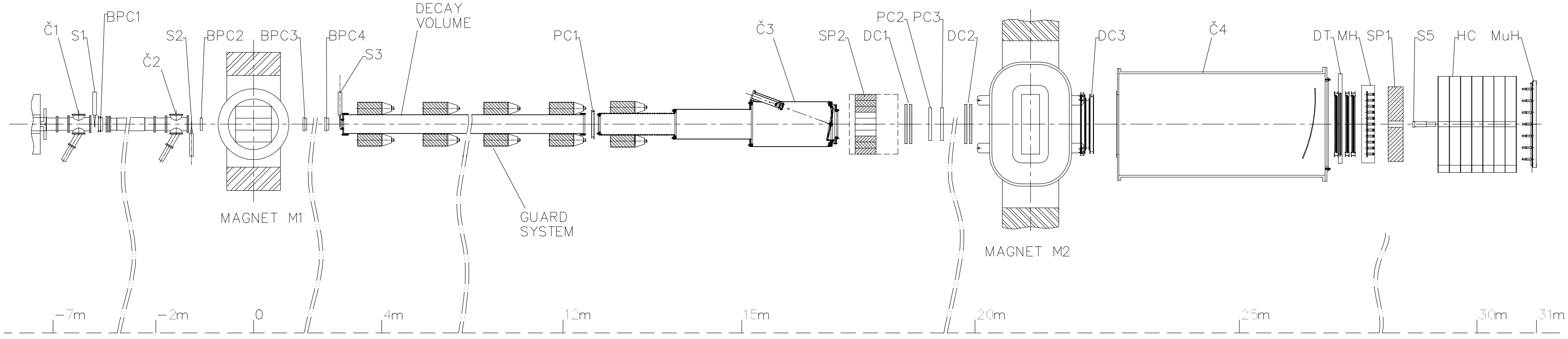
Recent ISTRA+ results on kaon decays

IHEP, Protvino; INR, Moscow collaboration

ISTRA+ setup at U-70 PS, Protvino, Russia



$p \sim -25$ GeV ; $\Delta p/p \sim 1.5\%$; $K^- \sim 3\%$; $I \sim 3 \cdot 10^6/1.9$ sec

$T = S_1 \cdot S_2 \cdot S_3 \cdot \bar{S}_4 \cdot \check{C}_0 \cdot \bar{\check{C}}_1 \cdot \bar{\check{C}}_2 \cdot \bar{S}_5 \cdot (\Sigma_{SP1} >$mip)

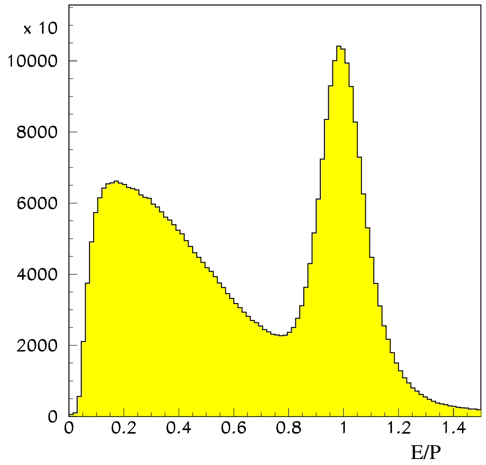
ISTRA+ statistics, experimental program

In 1999-2001 in 3 runs $\sim$ 1000 M events were recorded.

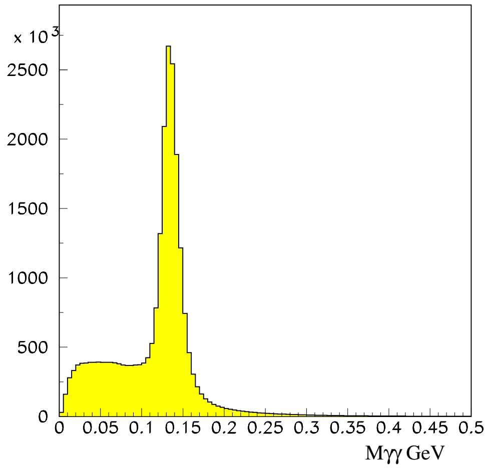
This statistics is complemented by $\sim$ 500 M Geant-3 MC events.

- High statistics study of the decays $K^- \to e^-(\mu^-)\nu\pi^0$
  K_{e3}: Phys. Lett. B589(2004)111 ; $K_{\mu3}$: Phys. Lett. B581(2004)31
- Measurement of the Dalitz plot slopes for $K^- \to \pi^-\pi^0\pi^0$
  Phys. Lett. B567(2003)159 (final result).
- Search for light pseudoscalar sgoldstino in $K^- \to \pi^-\pi^0 P$
  Preliminary result in hep-ex 0308061; IHEP Preprint 2003-20.
- Search for the decay $K^- \to \mu^-\nu\pi^0\gamma$
- Study of the decay $K^- \to \pi^-\pi^0\gamma$
- Study of the decay $K^- \to e\nu\gamma$

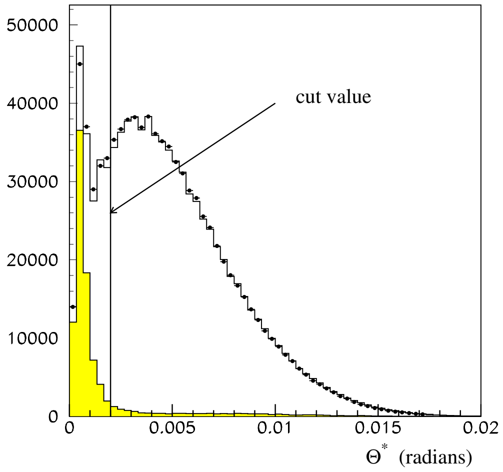
Ke3 decay selection



The E/P plot.



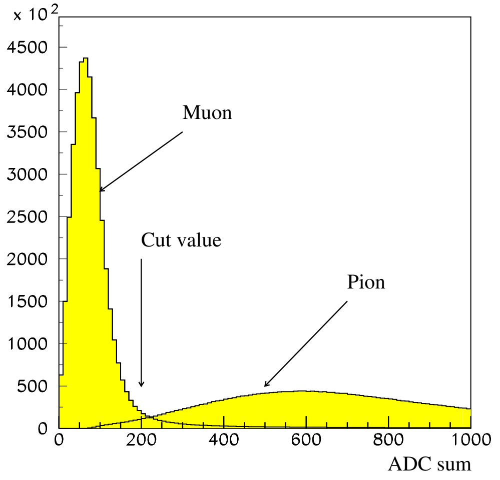
The $\gamma\gamma$ mass spectrum.

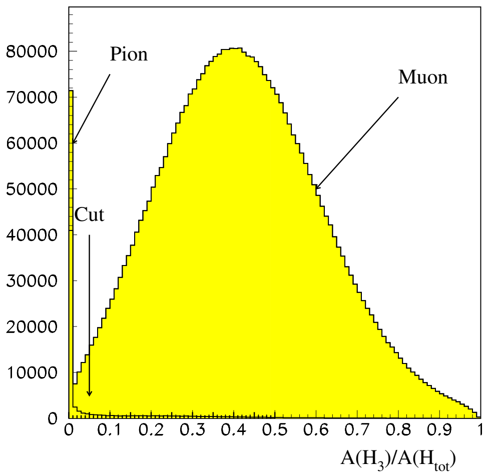


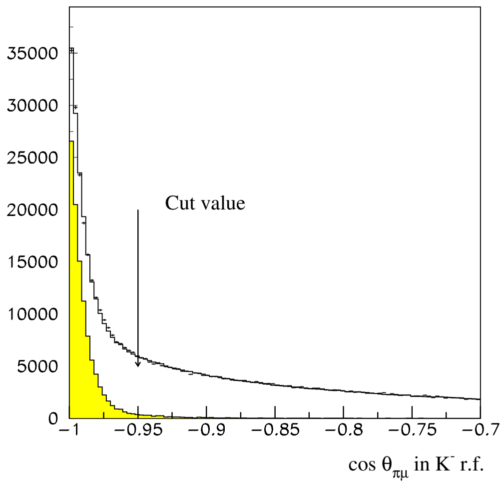
Angle $\vec{P}_K \wedge (\vec{P}_e + \vec{P}_{\pi^0})$.

920 K events selected, background $\sim 2.1\%$

$K\mu3$ decay selection







ADC sum in HCAL | HCAL last 3 layers to Σ ratio | Angle $\pi - \mu$ in CMS

537 K events selected, background $\sim 0.3\%$

K_{l3} phenomenology

$$M = \frac{G_F V_{us}}{2}\bar{u}(p_\nu)(1+\gamma^5)[2m_K f_S + \frac{2if_T}{m_K}\sigma_{\alpha\beta}p_K^\alpha p_\pi^\beta - [(p_K+p_\pi)_\alpha f_+ + (p_K-p_\pi)_\alpha f_-]\gamma^\alpha]v(p_l)$$

Dalitz-plot density:

$$\rho(E_\pi, E_l) \sim A\cdot|V|^2 + B\cdot Re(V^*S) + C\cdot|S|^2$$

$$V = f_+ + (m_l/m_K)f_T \quad ; \quad S = f_S + (m_l/2m_K)f_- + \left(1 + \frac{m_l^2}{2m_K^2} - \frac{2E_l}{m_K} - \frac{E_\pi}{m_K}\right)f_T$$

$$A = m_K(2E_lE_\nu - m_K\Delta E_\pi) - m_l^2(E_\nu - \tfrac{1}{4}\Delta E_\pi)\ ;\ B = m_l m_K(2E_\nu - \Delta E_\pi)\ ;\ C = m_K^2\Delta E_\pi$$

$$(\Delta E_\pi = E_\pi^{max} - E_\pi\ ;\ E_\pi^{max} = \frac{m_K^2 - m_l^2 + m_\pi^2}{2m_K}\ )$$

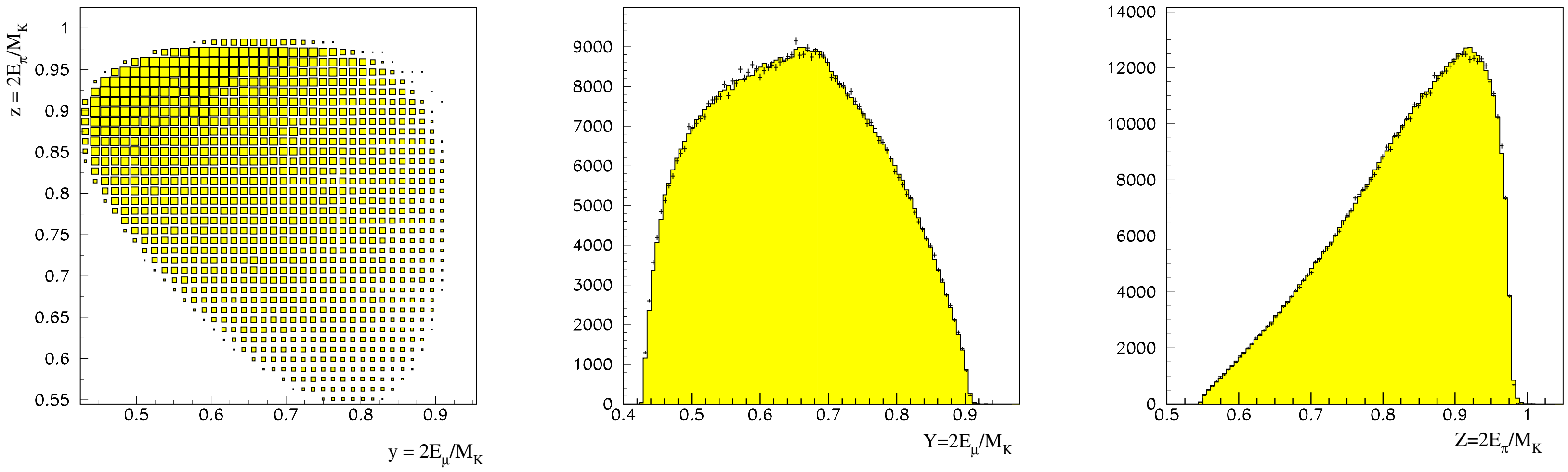
t-dependance of the formfactors:

$$f_0(t) = f_+(t) + \frac{t}{m_K^2 - m_\pi^2}f_-(t)$$

$$f_+(t) = f_+(0)(1 + \lambda_+ t/m_\pi^2 + \lambda_+^{'} t^2/m_\pi^4)\ ;\ f_0(t) = f_+(0)(1 + \lambda_0 t/m_\pi^2 + \lambda_0^{'} t^2/m_\pi^4) \Rightarrow$$

$$f_- = f_+(0)\frac{m_K^2 - m_\pi^2}{m_\pi^2}(\lambda_0 - \lambda_+ + \frac{t}{m_\pi^2}(\lambda_0^{'} - \lambda_+^{'}))$$

K_{l3} decay, analysis method



Dalitz-plot is subdivided into 40 $\times$40 bins ; $\rho(y,z)$ obeys a property of quazi-factorization, i.e

$$\rho(y,z) = \sum_{\alpha=1,18} F_\alpha(\lambda_+, \lambda_+^{'}, \lambda_0, \lambda_0^{'}, f_S, f_T)\cdot K_\alpha(y,z), \Rightarrow$$

$$r(i,j) = \sum_{\alpha=1,18} F_\alpha(\lambda_+, \lambda_+^{'}, \lambda_0, \lambda_0^{'}, f_S, f_T)\cdot W_\alpha(i,j)$$

The rad. cor. V.Cirigliano et al., Eur. Phys. J. C23(2002)121 are taken into account for Ke3

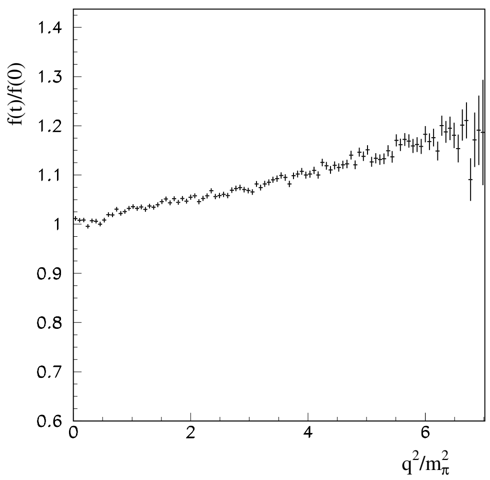
$$\chi^2 = 2\sum_j n_j \ln\left[\frac{n_j}{r_j}\left(1-\frac{1}{m_j+1}\right)\right] + 2\sum_j (n_j+m_j+1)\ln\left((1+\frac{r_j}{m_j})/(1+\frac{n_j}{m_j+1})\right),$$

n_j, r_j and m_j are data , expected and MC events. For large m_j it reduces to

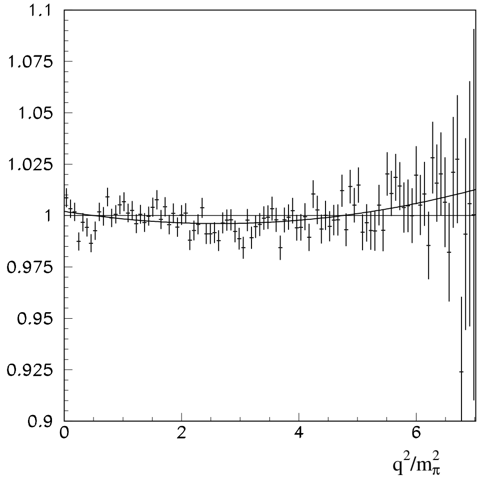
$$\chi^2 = \sum_j [2(r_j - n_j) + 2n_j \ln n_j/r_j]$$

K_{e3} decay, fit results

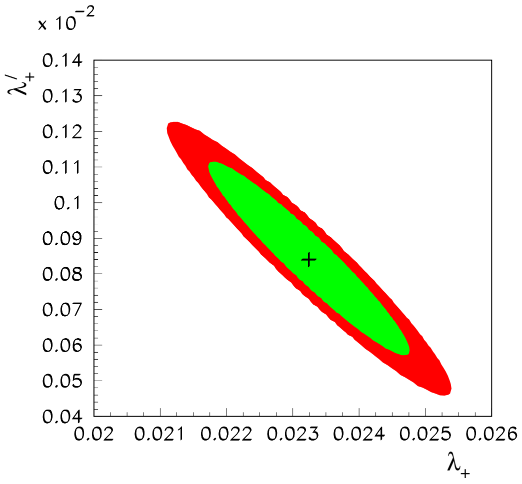
$\lambda_+ \times 10^3$	$\lambda'_+ \times 10^3$	$f_T/f_+(0)$ %	$f_S/f_+(0)$ %	$\Delta\chi^2$
27.74 ± 0.47	$0.$	$0.$	$0.$	$0.$
23.24 ± 1.52	0.84 ± 0.27	$0.$	$0.$	$-9.8.$
23.24 ± 1.52	0.84 ± 0.27	$0.$	$-0.37^{+0.66}_{-0.56}$	-9.9
23.24 ± 1.52	0.84 ± 0.27	-1.2 ± 2.1	$0.$	-9.9



$f_+(t)/f_+(0)$



λ'_+-nonlinearity



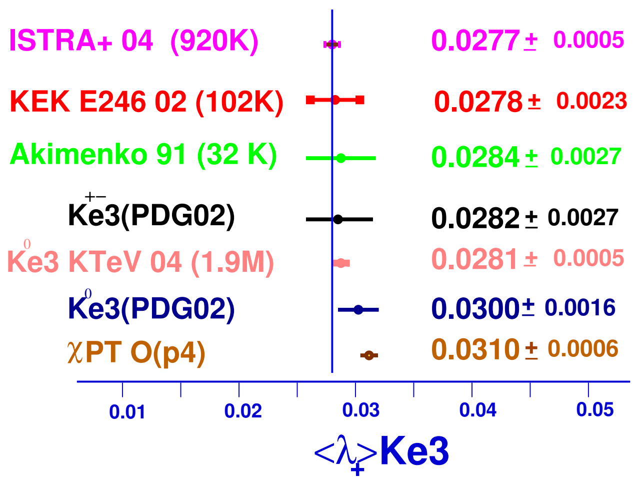
$\lambda_+ - \lambda'_+$ correlation

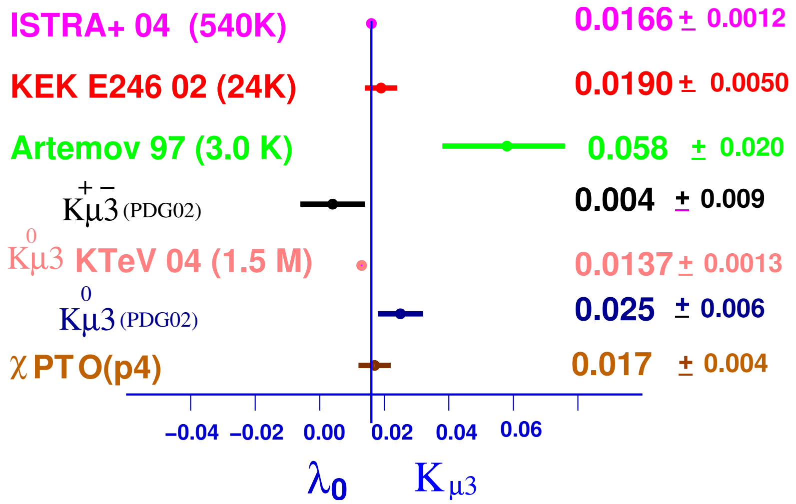
$K_{\mu 3}$ decay, fit results

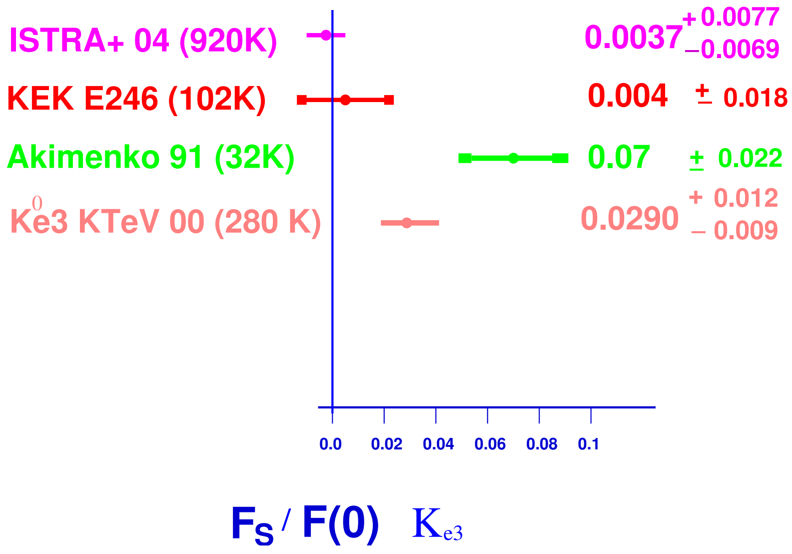
$\lambda_+ \times 10^3$	$\lambda_0 \times 10^3$	$\lambda_+^{'} \times 10^3$	$\lambda_0^{'} \times 10^3$	$f_T/f_+(0)\%$	$f_S/f_+(0)\%$	Fit prob.
27.7 ± 1.3	18.3 ± 1.1	$0.$	$0.$	$0.$	$0.$	0.425
21.5 ± 6.0	16.0 ± 2.1	1.0 ± 1.0	$0.$	$0.$	$0.$	0.451
27.6 ± 1.4	17.0 ± 5.9	$0.$	0.2 ± 0.8	$0.$	$0.$	0.421
27.6 ± 1.4	18.3 ± 1.1	$0.$	$0.$	-0.07 ± 0.71	$0.$	0.422
27.7 ± 1.3	17.0	$0.$	$0.$	$0.$	0.17 ± 0.14	0.421

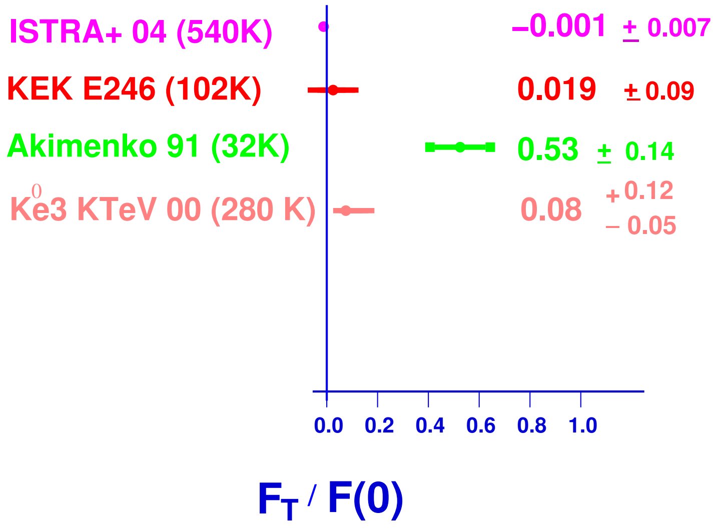
Combined $K_{e3} - K_{\mu 3}$ fits

$\lambda_+ \times 10^3$	$\lambda_0 \times 10^3$	$\lambda_+^{'} \times 10^3$	$\lambda_0^{'} \times 10^3$	$f_T/f_+(0)\%$	$f_S/f_+(0)\%$	$\Delta\chi^2$
27.7 ± 0.4	18.3 ± 1.0	$0.$	$0.$	$0.$	$0.$	$0.$
23.1 ± 1.5	16.6 ± 1.1	0.86 ± 0.26	$0.$	$0.$	$0.$	-10.7
23.1 ± 1.5	16.8 ± 5.8	0.86 ± 0.26	0.03 ± 0.8	$0.$	$0.$	-10.8
23.1 ± 1.5	16.6 ± 1.1	0.86 ± 0.26	$0.$	0.1 ± 0.65	$0.$	-10.8
23.1 ± 1.5	17.0	0.87 ± 0.26	$0.$	$0.$	0.07 ± 0.15	-10.2


ISTRA+ 04 (920K) 0.0277 ± 0.0005
KEK E246 02 (102K) 0.0278 ± 0.0023
Akimenko 91 (32 K) 0.0284 ± 0.0027
Ke3(PDG02) 0.0282 ± 0.0027
Ke3 KTeV 04 (1.9M) 0.0281 ± 0.0005
Ke3(PDG02) 0.0300 ± 0.0016
χPT O(p4) 0.0310 ± 0.0006
0.01
0.02
0.03
0.04
0.05
<λ+>Ke3


ISTRA+ 04 (540K) 0.0166 ± 0.0012
KEK E246 02 (24K) 0.0190 ± 0.0050
Artemov 97 (3.0 K) 0.058 ± 0.020
Kμ3 (PDG02) 0.004 ± 0.009
Kμ3 KTeV 04 (1.5 M) 0.0137 ± 0.0013
Kμ3 (PDG02) 0.025 ± 0.006
χ PT O(p4) 0.017 ± 0.004
−0.04
−0.02
0.00
0.02
0.04
0.06
λ0 Kμ3


ISTRA+ 04 (920K) 0.0037 +0.0077 −0.0069
KEK E246 (102K) 0.004 ± 0.018
Akimenko 91 (32K) 0.07 ± 0.022
Ke3 KTeV 00 (280 K) 0.0290 + 0.012 − 0.009
0.0
0.02
0.04
0.06
0.08
0.1
FS / F(0) Ke3


ISTRA+ 04 (540K) −0.001 ± 0.007
KEK E246 (102K) 0.019 ± 0.09
Akimenko 91 (32K) 0.53 ± 0.14
Ke3 KTeV 00 (280 K) 0.08 +0.12 − 0.05
0.0
0.2
0.4
0.6
0.8
1.0
FT / F(0)

$K_{e3} - K_{\mu 3}$ decays, Summary and conclusions

The $<\lambda_+>$- average slope parameter of the vector form-factor $f_+(t)$ has been measured with the best world accuracy:

$$<\lambda_+>= (27.7 \pm 0.44(stat) \pm 0.3(syst)) \times 10^{-3} \Longleftrightarrow \lambda_+^{th}(\chi PT\ O(p^4)) = (31.0 \pm 0.6) \cdot 10^{-3}$$

A significant nonlinearity in $f_+(t)$ is observed for the first time:

$$\lambda_+^{'} = (0.86 \pm 0.26(stat) \pm 0.3(syst)) \times 10^{-3} \Longleftrightarrow \lambda_+^{'}(\chi PT\ O(p^6)) = (1.12 \pm 0.1) \cdot 10^{-3}$$

With this quadratic term the linear slope, which has a meaning of $df_+(t)dt|_{t=0}$ is measured to be:

$$\lambda_+ = (23.1 \pm 1.5(stat) \pm 0.3(syst)) \times 10^{-3}$$

The λ_0 slope parameter of the scalar form-factor $f_0(t)$ has been measured with good precision for the first time:

$$\lambda_0 = (16.6 \pm 1.(stat) \pm 0.6(syst)) \times 10^{-3} \Longleftrightarrow \lambda_0^{th}(\chi PT\ O(p^4)) = (17. \pm 4.) \cdot 10^{-3}$$

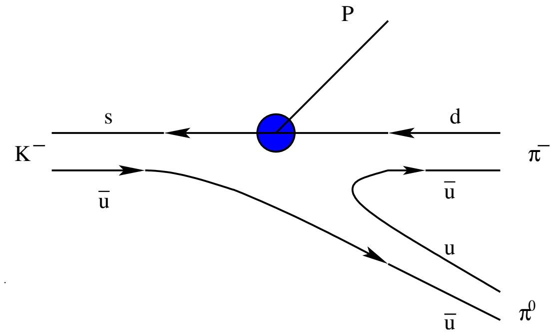
Best world limits on possible tensor and scalar couplings have been derived:

$$f_T/f_+(0) = (0.1 \pm 0.65(stat) \pm 0.3(syst)) \times 10^{-2} \Longrightarrow \Lambda_{LQ} > 3TeV(90\%CL)$$

$$f_S/f_+(0) = (0.3 \pm 0.6(stat) \pm 0.4(syst)) \times 10^{-2} \Longrightarrow tg(\beta)/m_H < .5GeV^{-1}(90\%CL)$$

Search for light pseudoscalar sgoldstino in $K^- \to \pi^- \pi^0 P$ decay

In models with spontaneous supersymmetry breaking the superpartners of a Goldstone fermion, pseudoscalar P and scalar S goldstinos, should exist. In some gravity-mediated and gauge-mediated theories $m_{P,S}$ ∼MeV, i.e P,S could be observed in K decays. Moreover, if P,S interactions with quarks conserve parity, as in left-right extensions of MSSM, and P is lighter than S, so that $m_S > (m_K - m_\pi)$ and $m_P < (m_K - 2m_\pi)$, sgoldstinos can be observed in $K \to \pi\pi P$, rather than in much better constrained $K \to \pi S$. The phenomenology of light S,P is considered in D.S.Gorbunov, V.A.Rubakov PR D64(2001). If P violates quark flavor and conserve parity, low energy interactions of P is given by $L = -P \cdot (h_{ij}^D \cdot \overline{d}_i i\gamma^5 d_j + h_{ij}^U \cdot \overline{u}_i i\gamma^5 u_j)$; $\Delta m(K_L, K_S)$ and $\epsilon \Rightarrow$



$|h_{12}| \leq 7 \cdot 10^{-8}$; $|Re(h_{12}) \cdot Im(h_{12})| < 1.5 \cdot 10^{-17}$

Depending on phase of h_{12}, these gives:

$Br(K^- \to \pi^- \pi^0 P) \leq 1.5 \cdot 10^{-6} \div 4 \cdot 10^{-4}$.

P decays to $\gamma\gamma$ or $l^+ l^-$ ($\gamma\gamma$ dominates) . Depending on $g_\gamma = \frac{1}{2\sqrt{2}} \frac{M_{photino}}{F}$, P has different lifetime. In our search we assume that P decays outside the detector, i.e. is "invisible".

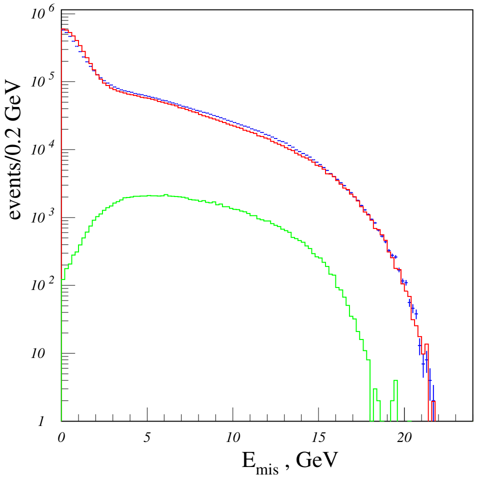
The existing exp. limit on $Br(K^- \to \pi^- \pi^0 P)$ is $4 \cdot 10^{-5}$ (90% CL) , the limit for S is $\sim 10^{-10}$

Event selection

The signature for $K^- \to \pi^- \pi^0 P$ is :

- Missing energy $E_K - E_{\pi^-} - E_{\pi^0} > 0$; Peak in the MMS $(P_K - P_{\pi^-} - P_{\pi^0})^2$

A set of cuts is developed to suppress $K \to \pi^- \pi^0$; $K \to \pi^- \pi^0 \pi^0$; $K \to \mu^- \nu \pi^0$;$K \to e^- \nu \pi^0$:



1 . One charged track and two showers in forward ECAL .

2 . π identification, based on HCAL and ECAL. The efficiency(80%) and muon admixture(2%) of this selection known from $K \to \pi\pi^0$ and $K \to \mu\nu$.

3 . $E_{mis} = E_{beam} - E_{\pi^-} - E_{\pi^\circ} > 3$ GeV.

4 . $p^*_{\pi^-} < 180$ MeV ;$p^*_{\pi^-}$ - pion momentum in K^- c.m.s..

5 . The “Veto” cut: no signals above noise threshold in Veto system and large angle ECAL(SP_2).

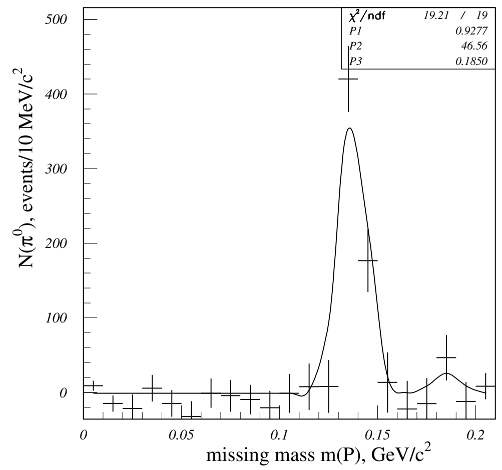
Background suppression of 300 with efficiency to signal $\epsilon = 30\%$ is achieved, 30K events survived. As a result of the cuts, the π^0 signal practically disappears from the $\gamma\gamma$ mass spectrum for certain missing mass m_P intervals. This allows to perform an effective background subtraction procedure.

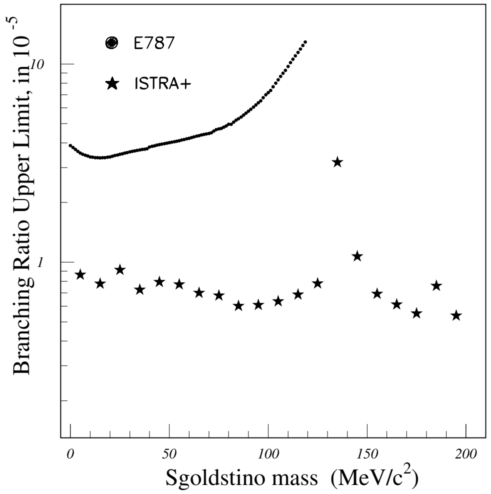
Results, Conclusions

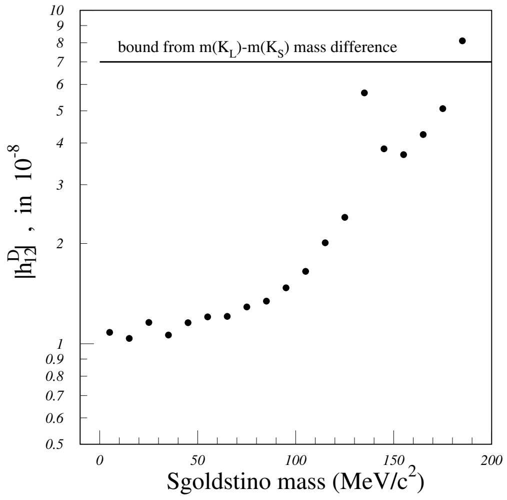
No significant signal is observed in the background subtracted MMS. To obtain UL at different m_P , MMS is fitted by the signal Gaussian ($\sigma = 11.1$ MeV/c^2) and the background(Gaussian for $\pi^- \pi^\circ (\pi^\circ)$ + constant term). One-sided 90% upper limits for N_{sig} and Br are calculated as:

$$N_{UL} = max(N_{sig}, 0) + 1.28 \cdot \sigma; \quad UL = \frac{N_{UL} \cdot Br(K_{\pi 2}) \cdot \varepsilon(K_{\pi 2})}{N(K_{\pi 2}) \cdot \varepsilon},$$

$N(K_{\pi 2})$ is the number of $K^- \to \pi^- \pi^\circ$ decays($\sim$ 6 M); ε, $\varepsilon(K_{\pi 2})$- signal and $K_{\pi 2}$ efficiencies.





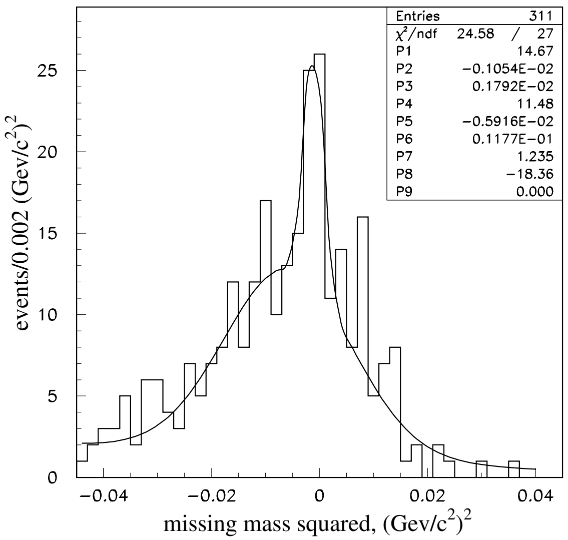


Our result improves that of E787. It also improves the TH constraints on $|h^D_{12}|$ from $\Delta M(K_L, K_S)$.

Observation of the decay $K^- \to \mu^- \nu \pi^0 \gamma$

- Missing energy $E_K - E_{\mu^-} - E_{\pi^0} - E_\gamma > 0$
- Peak at -0- in the MMS $(P_K - P_{\mu^-} - P_{\pi^0} - P_\gamma)^2$

A set of cuts is developed to suppress $K \to \pi^- \pi^0$; $K \to \pi^- \pi^0 \pi^0$; $K \to \mu^- \nu \pi^0$;$K \to e^- \nu \pi^0$



1. 1 charged track and 3 showers with $E_\gamma > 1$GeV in SP_1
2. μ identification, based on HCAL and ECAL
3. $E_{mis} = E_{beam} - E_{\pi^-} - E_{\pi^\circ} > 0$ GeV
4. p^*_π - charged track momentum in c.m.s.> 120MeV
5. $cos\theta^*_{\pi^- \pi^0} > -0.8$, θ^* - c.m.s. angle; $\phi_{\pi^- \pi^0} < 3.0$, ϕ is the acomplanarity angle in lab. system
6. The “Veto” cut: no signals above noise threshold in Veto system and large angle ECAL(SP$_2$)($z < 1200$cm.)

About 35 events are seen above background . The normalization on $K_{\mu 3}$ and $K_{\pi 2}$ gives:
$Br = (4.9 \pm 1.59 \pm 1.4) \times 10^{-5} \Leftrightarrow Br_{th} \sim 2 \times 10^{-5} (E_\gamma > 20$MeV)