Recent KLOE Results

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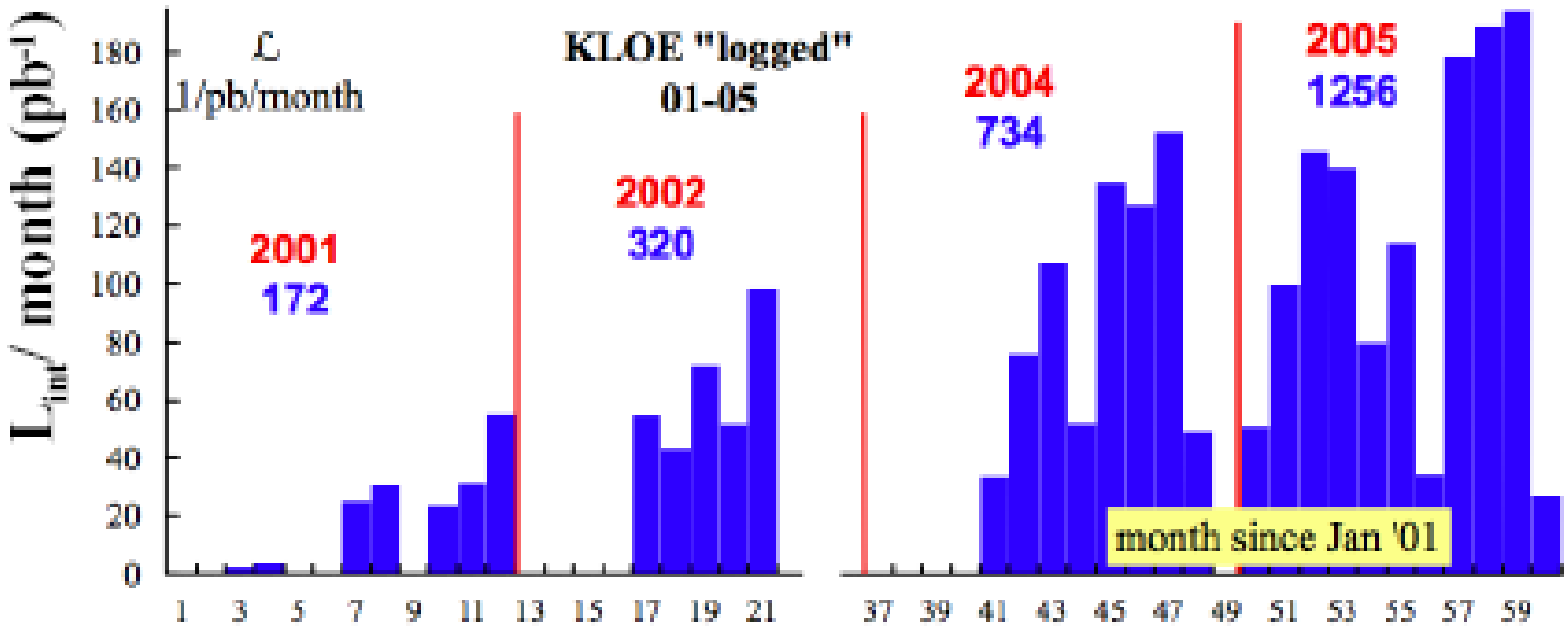
on behalf of the KLOE Collaboration
Les Rencontres de Physique, La Thuile, March 4 – 10, 2007

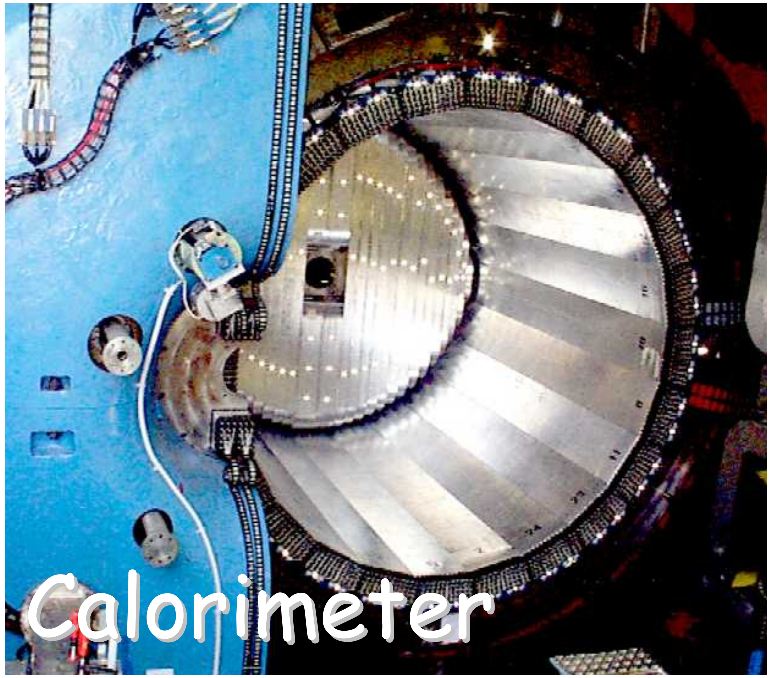
Overview of KLOE data

- data taking for KLOE experiment, years 2001-2005, now run completed



- ~ 2.5 fb^{-1} integrated @ $\sqrt{s}=M(\phi)$

KLOE detector performance



$\sigma_E/E \cong 5.7\% /\sqrt{E(GeV)}$

$\sigma_t \cong 54$ ps $/\sqrt{E(GeV)} \oplus 50$ ps
(relative time between clusters)

$\sigma_{\gamma\gamma} \sim 2$ cm (π^0 from $K_L \to \pi^+\pi^-\pi^0$)

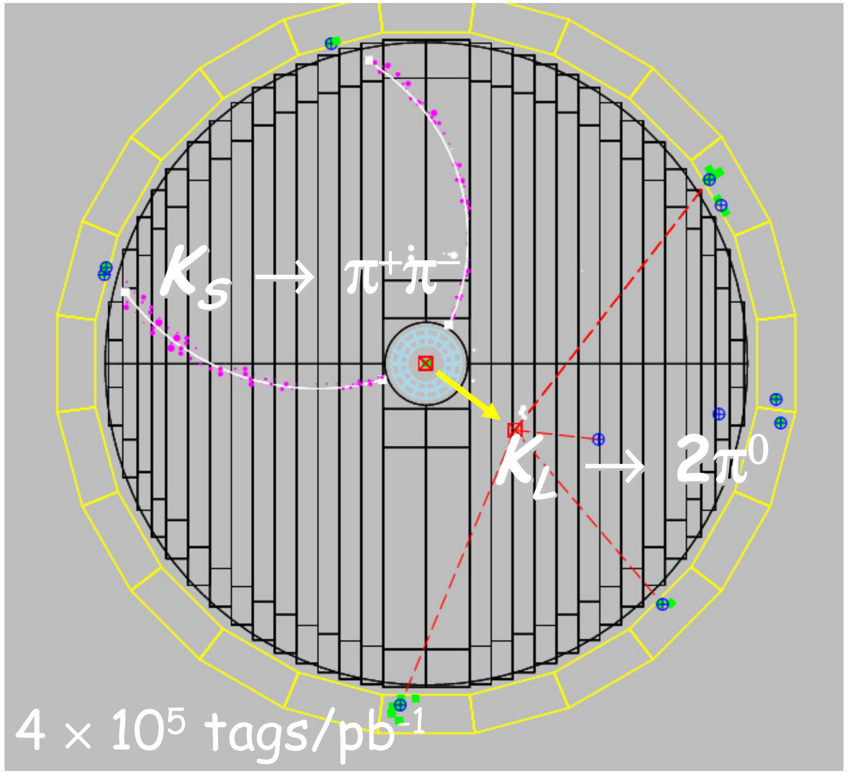
$\sigma_p/p \cong 0.4$ % (tracks with $\theta > 45°$)

$\sigma_x^{hit} \cong 150\ \mu m$ (xy), 2 mm (z)

$\sigma_x^{vertex} \sim 1$ mm

Tagging of K_L K_S beams

K_L tagged
by $K_S \to \pi^+\pi^-$ vertex at IP

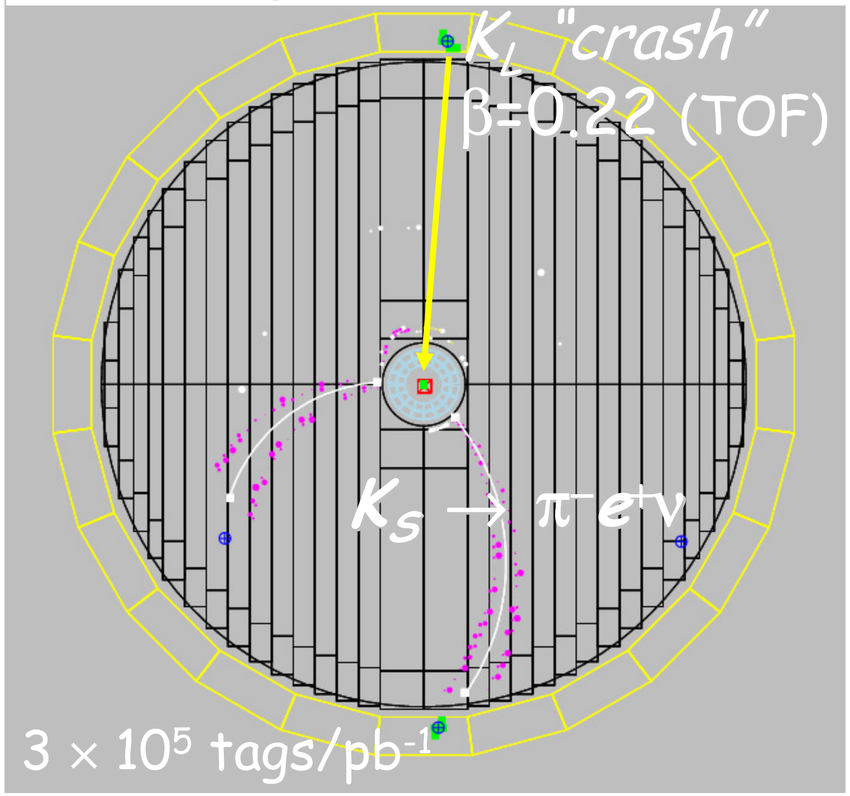


ε ~ **70%** (mainly geometrical)

K_L angular resolution: ~ 1°

K_L momentum resolution: ~ 1 MeV

K_S tagged
by K_L interaction in EmC



ε ~ **30%** (mainly geometrical)

K_S angular resolution: ~ 1° (0.3° in ϕ)

K_S momentum resolution: ~ 1 MeV

Recent KLOE results

results from kaon decays analyses published by KLOE in 2006

✓ absolute BR's for 4 main K_L channels and τ_L	PLB 632 (2006) 43
✓ form factor slopes for $K_L e3$ decays	PLB 636 (2006) 166
✓ BR's and charge asymmetry for $K_S e3$	PLB 636 (2006) 173
✓ precise measurement of $\Gamma(\pi^+\pi^-(\gamma))/\Gamma(\pi^0\pi^0)$	EPJ C48 (2006) 767
✓ absolute BR for $K^+ \to \mu\nu(\gamma)$ decay	PLB 632 (2006) 76
✓ absolute BR for $K_L \to \pi^+\pi^-(\gamma)$ decay	PLB 638 (2006) 140
✓ determination of CP, CPT parameters of K^0 system via BSR and data from KLOE	JHEP 122006011(2006)
✓ test of QM and CPT symmetry	PLB 642(2006)315

a couple of preliminary measurements have been announced

✓ absolute BR's $K^\pm_{l3}$ decays, $K^\pm$ lifetime

analysis close to be completed

✓ absolute BR's $K^\pm \to \pi^\pm\pi^0$

CPT test: the Bell-Steinberger relation

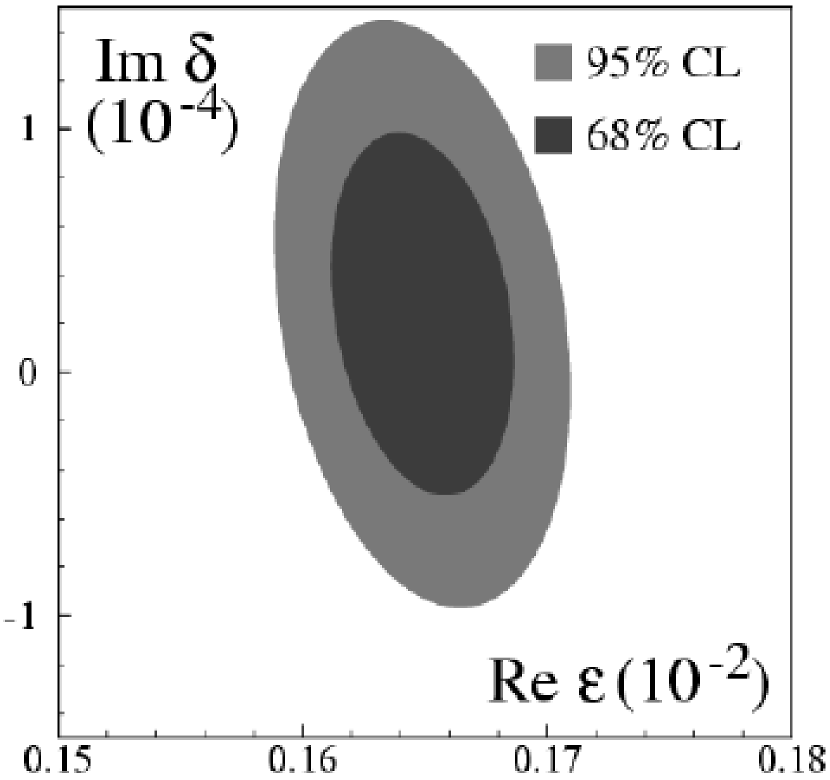
K_S K_L observables can be used for the CPT test from unitarity

$$(1 + i \tan \phi_{SW}) \, [\mathrm{Re}\,\varepsilon - i\, \mathrm{Im}\,\delta] = \frac{1}{\Gamma_S} \sum_f A^*(K_S \to f)\, A(K_L \to f) = \sum_f \alpha_f$$

after CPLEAR measurements (2001)

$$\mathrm{Re}(\epsilon) = (164.9 \pm 2.5) \times 10^{-5}$$

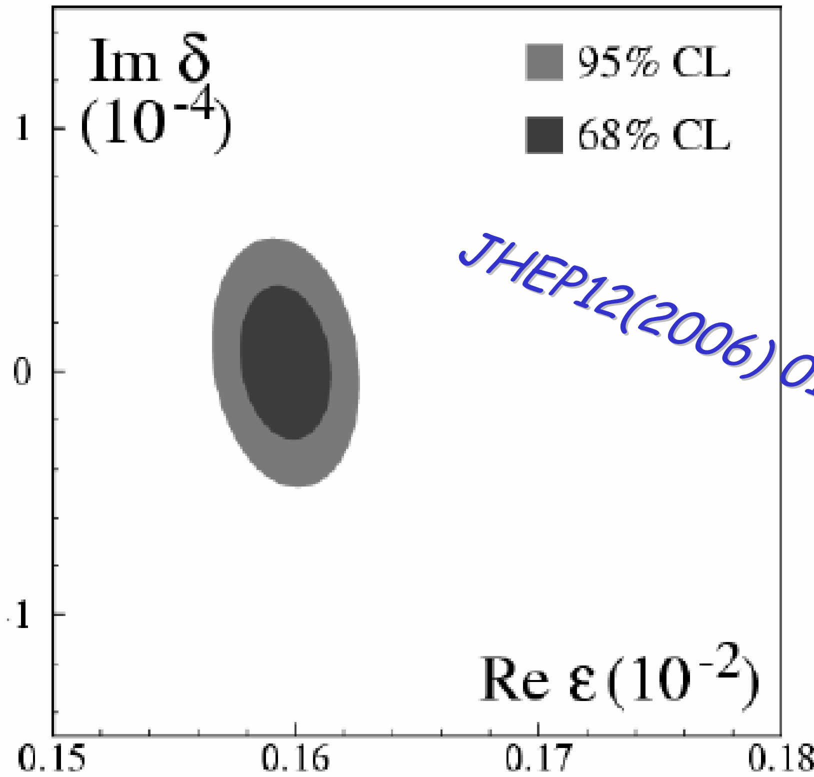
$$\mathrm{Im}(\delta) = (\ 2.4 \pm 5.0) \times 10^{-5}$$



after KLOE measurements (2006)

$$\mathrm{Re}(\epsilon) = (159.6 \pm 1.3) \times 10^{-5}$$

$$\mathrm{Im}(\delta) = (\ 0.4 \pm 2.1) \times 10^{-5}$$



JHEP12(2006) 011

Preliminary results from KLOE

- BR ($K_S \rightarrow e^+e^-$)
- BR ($K_S \rightarrow \gamma\gamma$)
- BR ($K_L \rightarrow e\pi\nu\gamma$)
- $K_{L\mu3}$ form factor slope λ_0

Analysis of $K_S \to e^+e^-$

SM prediction is low but precise BR($K_S \to e^+e^-$) = 1.6×10^{-15} *[Ecker, Pich 91]*
leaving room for possible new physics effects to be detected

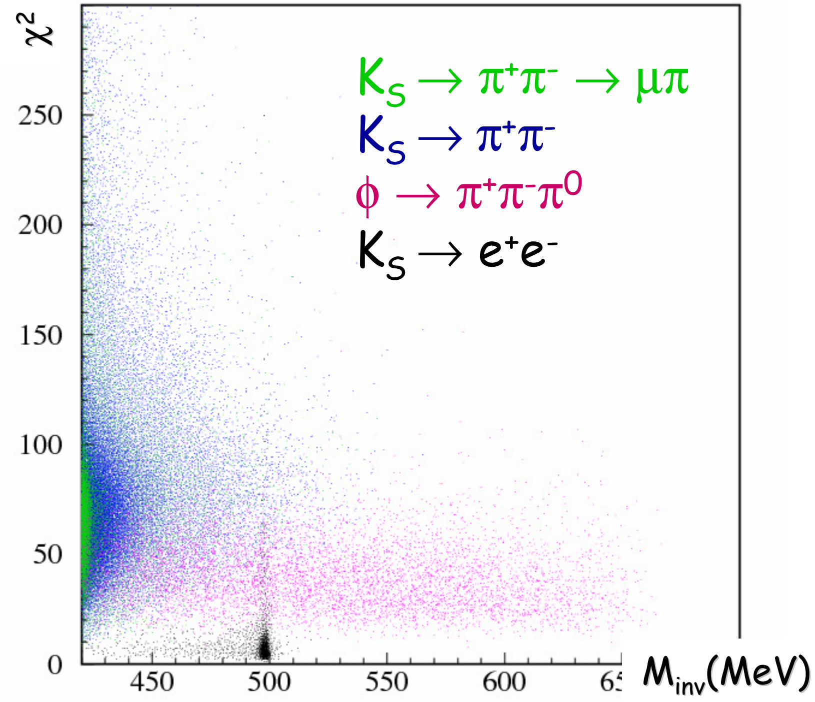
event preselection (1.32 fb^{-1})

- K_S tagged by K_L crash
- 2 tracks from IP to EmC

to identify the signal we build a χ^2-like variable based on

- sum and difference of (T_{clu}-ToF) of the 2 particles
- E/p of both particles
- transverse distance between track impact point and the closest cluster, for both particles

M_{inv} is evaluated in e^+e^- hypothesis



further cuts on

- P* (π hypo) in the K_S rest frame > 220 MeV
- M_{miss} to reject residual $\pi^+\pi^-\pi^0$ > 380 MeV

Analysis of $K_S \to e^+e^-$

$UL(\mu_{sig})$ evaluated numerically with Bayesian approach, taking into account background fluctuations *[NIM 212 (1983) 319-322]*

- optimization of signal box on MC: $(492 < M_{inv} < 504)$ MeV and $\chi^2 < 20$
- we find $N_{obs} = 3$ and $\mu_{BKG} = 7.1 \pm 3.6$ from these $UL(\mu_{sig}) = 4.3$ @90% CL
- without background subtraction $UL(\mu_{sig}) = 6.68$ @ 90% CL

✓ *normalize signal counts to* $K_S \to \pi\pi(\gamma)$ *counts in the same data set*

$$UL(BR) = UL(\mu_{sig}) \times \frac{\varepsilon_{\pi\pi}}{\varepsilon_{sig}} \times \frac{BR_{\pi\pi}}{N_{\pi\pi}}$$

$$\varepsilon_{sig} = \varepsilon_{presel} \times \varepsilon_{signal\ box} \times \alpha_{\gamma\text{-rad}} = 0.785 \times 0.888 \times 0.8 = 0.558$$

$$\varepsilon_{\pi\pi} = 0.6\ ,\ N_{\pi\pi} = 148174688$$

✓ $\alpha_{\gamma\text{-rad}}$ *acceptance of the radiated foton* $E^*_\gamma < 6$ *MeV*

CPLEAR: 1.4×10^{-7}

KLOE preliminary

$UL(\ BR(K_S \to e^+e^-(\gamma))\ ) = 2.1 \times 10^{-8}$ @ 90% CL

Analysis of $K_S \to \gamma\gamma$

BR($K_S \to \gamma\gamma$) is an important probe of χPT *[Phys.Rev.D 49 (1994) 2346]*

event preselection (1.6 fb^{-1})

- K_S tagged by K_L crash
- 2 and only 2 γ_{prompt} with

$$E\gamma > 7 MeV$$
$$\cos(\theta_{\gamma\gamma}) > 0.95$$
$$(T_\gamma - R/c) < 5\sigma_t$$

event selection

- kinematic fit

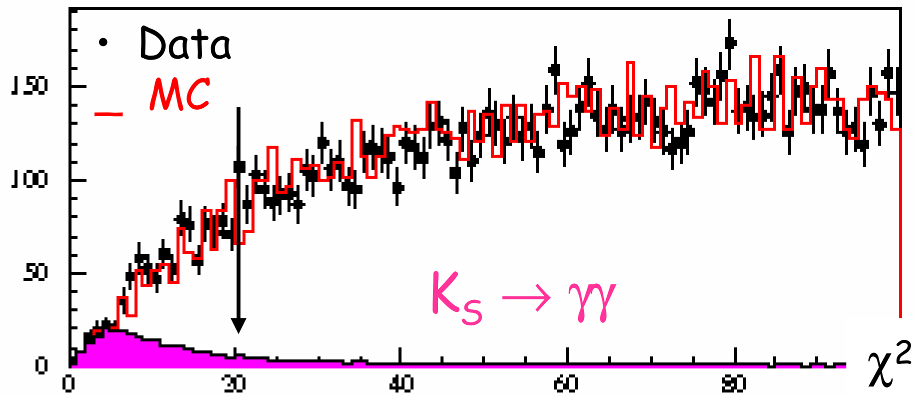
$$P_{KS}(K_L crash) = P_{KS}(\gamma\gamma)$$
$$M_{\gamma\gamma} = M_{KS}$$
$$T_\gamma = R/c \text{ for both } \gamma\text{'s}$$

- QCAL veto

$$BR = N_{\gamma\gamma} \times \frac{\varepsilon_{2\pi 0}}{\varepsilon_{sig}} \times \frac{BR_{2\pi 0}}{N_{2\pi 0}}$$

$\varepsilon_{\gamma\gamma} = \varepsilon_{presel} \times \varepsilon_{sel} \sim 0.83 \times 0.63 \sim 0.50$

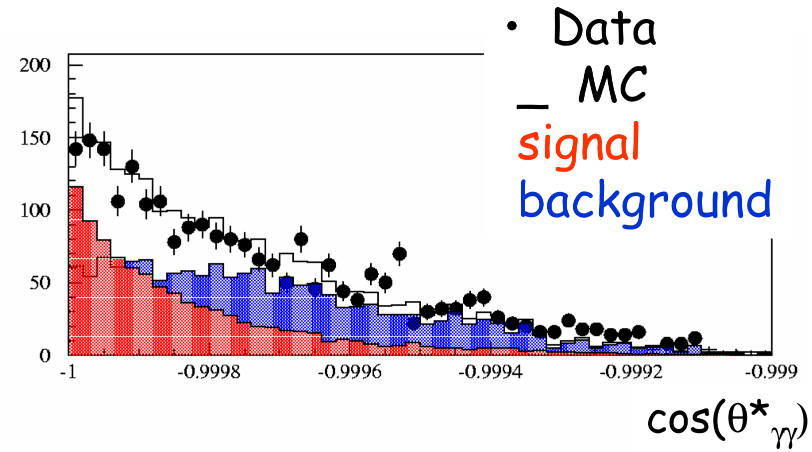
$\varepsilon_{2\pi 0} = 0.65$

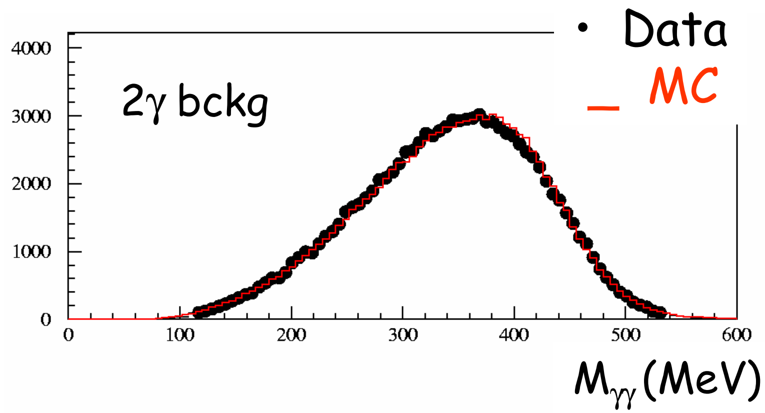


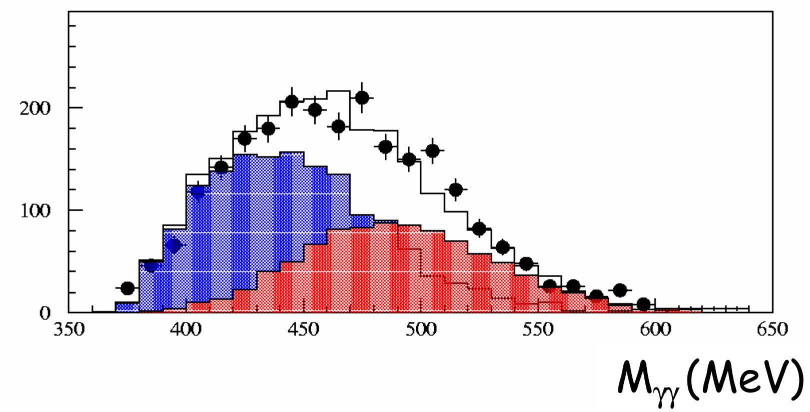
✓ *ε(QCAL veto) ~ 1 on signal apart from accidental losses*

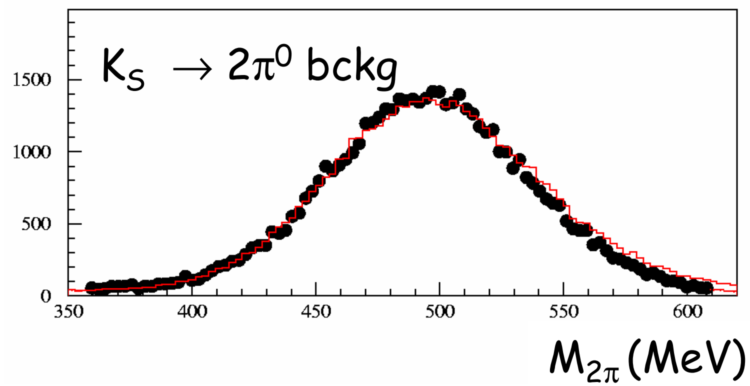
Analysis of $K_S \to \gamma\gamma$

- count signal events fitting the 2D plot of $M_{\gamma\gamma}$ and $\theta^*_{\gamma\gamma}$ in the K_S cms with MC shapes
- $K_L \to \gamma\gamma$ control sample selected to check the energy scale on data-MC



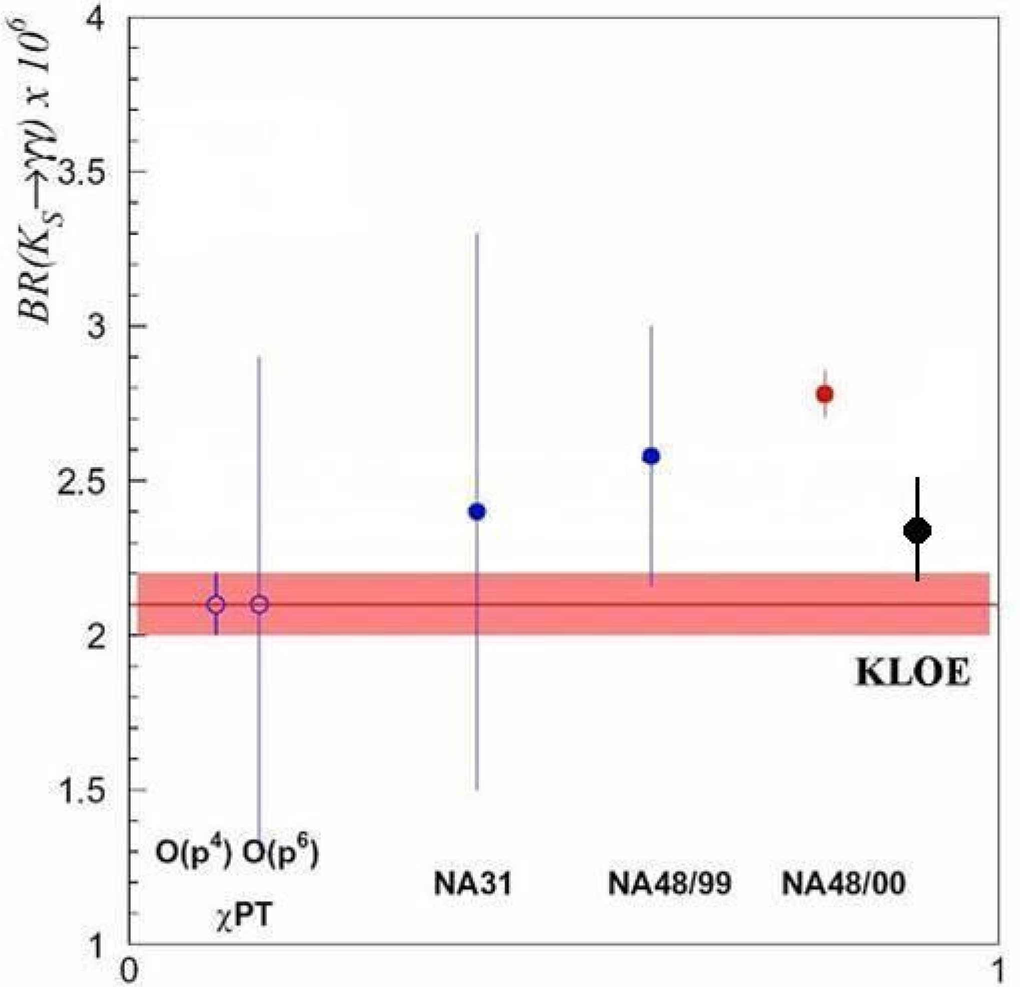






✓ *signal and normalization samples free from $K_L \to \gamma\gamma$ bckg*

Analysis of $K_S \to \gamma\gamma$



KLOE preliminary

$BR = (2.35 \pm 0.14) \times 10^{-6}$

- ✓ 2.7 σ from NA48 result
- ✓ 1.5 σ in agreement with χPT $\mathcal{O}(p^4)$ prediction

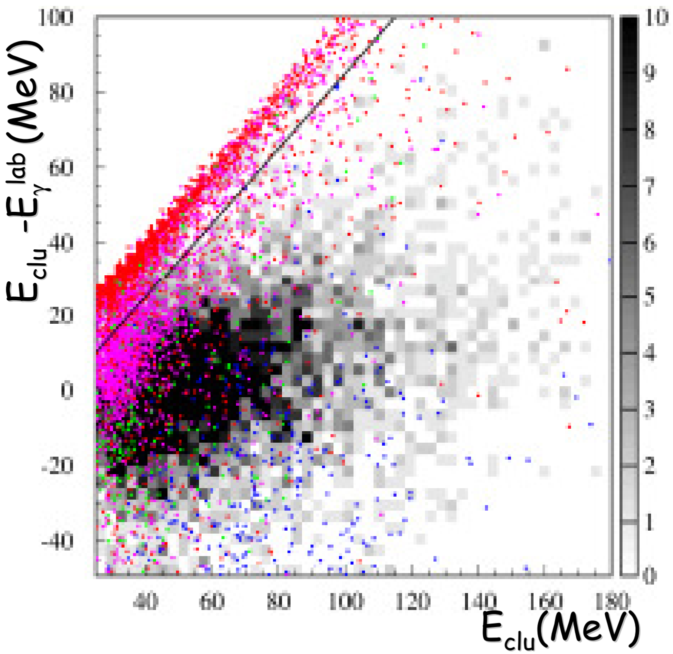
Analysis of $K_L \to \pi e \nu \gamma$

measurement of the BR and of the contribution due to the Direct Emission term in the γ spectrum

inclusive selection (328 pb^{-1})

- K_L tagged by $K_S \to \pi^+\pi^-$
- $(E_{miss}-cP_{miss})$ in different mass hypothesis to remove ~90% of bck
- ToF to separate e/π (after PID ~ 0.7% contamination)

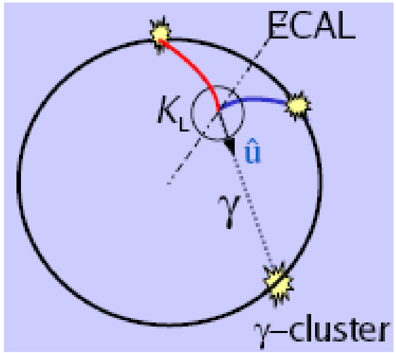
➔ 2×10^6 K_{e3}



Ke3γ out of acc.
not radiative K_{e3}
$\phi \to \pi^+\pi^-\pi^0$
Kμ3
Signal

radiative sample selection

- $K_L\gamma$ vtx -> comparing ToF $_{KL}$ and the γ-cluster time, it must be inside a 8σ sphere centered at the DCvtx
- cluster position to close the kinematic and evaluate Eγ -> $p^2_\nu = 0 = (p_K-p_\pi-p_e-p_\gamma)^2$

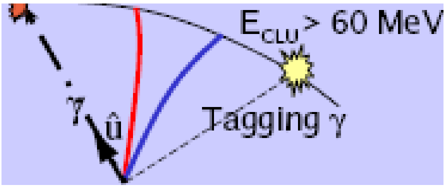


background reduction

- E_{clu}> 25 MeV to remove accidentals
- NN to remove
  Kμ3 trained with EmC infos
  $\pi^+\pi^-\pi^0$ trained with kinematic and EmC infos

Analysis of $K_L \to \pi e \nu \gamma$

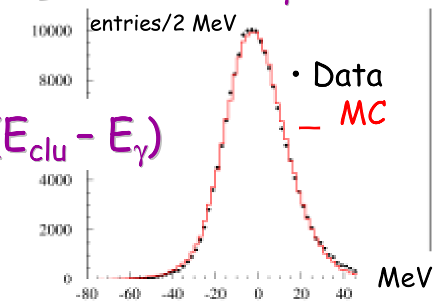
control sample from $K_L \to \pi^+\pi^-\pi^0$



- narrow window on M_{miss}
- $(E_{miss}\text{-}cp_{miss})$ in different masses hypothesis
- tagging γ with $E_{clu} > 60$ MeV
- same γ selection and $E\gamma$ evaluation as done for the signal -> $p^2_{\gamma\text{-tag}} = 0 = (p_K - p_\pi - p_e - p_\gamma)^2$

✓ to evaluate the Data/MC γ-efficiency correction as a function of E_γ
✓ to measure $K_L \gamma$ vtx, and E_γ resolutions

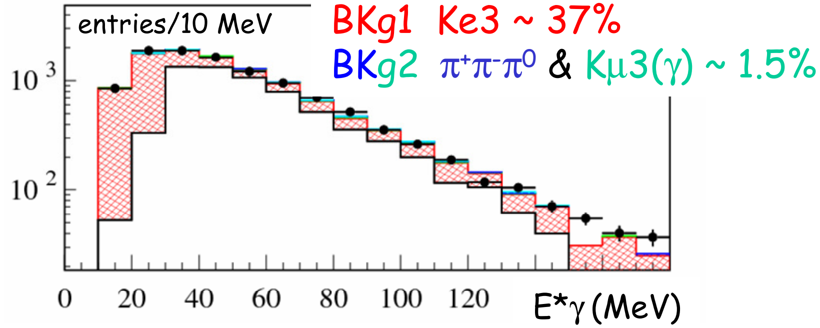
example $(E_{clu} - E_\gamma)$

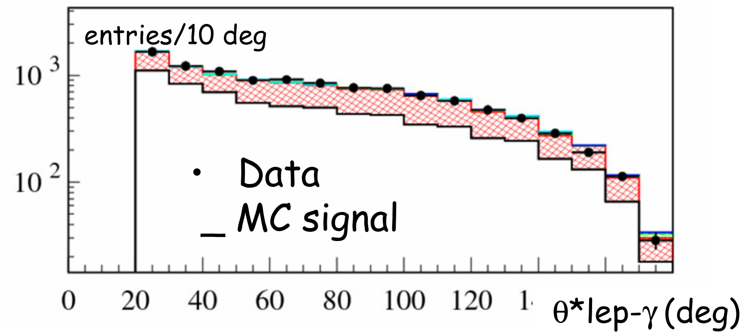


we measure →

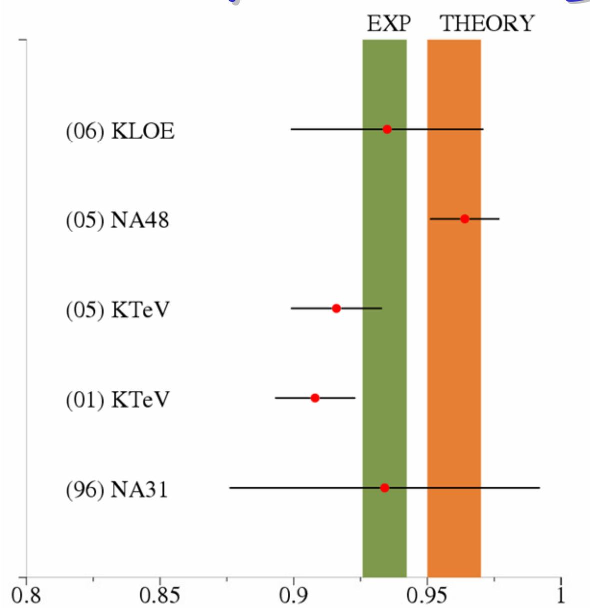
$$R = \frac{BR(Ke3\gamma;\ E^*\gamma > 30\ \text{MeV},\ \theta^*_{lep\text{-}\gamma} > 20^0)}{BR(Ke3(\gamma))}$$

- count signal and normalization events fitting the 2D plot of E^*_γ and $\theta^*_{lep\text{-}\gamma}$ with the MC shapes
- free parameters ➔ signal and BKg1
- BKg2 fixed (MC normalized to Data)





Analysis of $K_L \rightarrow \pi e \nu \gamma$



theory *[Gasser et al.,Eur.Phys.J. 40C,2005]*

fit on experimental results

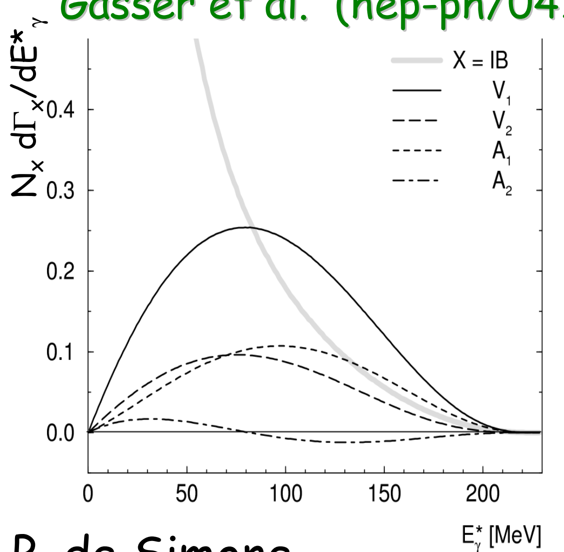
KLOE preliminary

$R = (0.92 \pm 0.02_{stat} \pm 0.02_{syst})\%$

statistical error will be soon improved by a factor 2 using the whole KLOE data set

DE-γ spectrum calculated in χPT $O(p^6)$

Gasser et al. (hep-ph/0412130)



KLOE preliminary

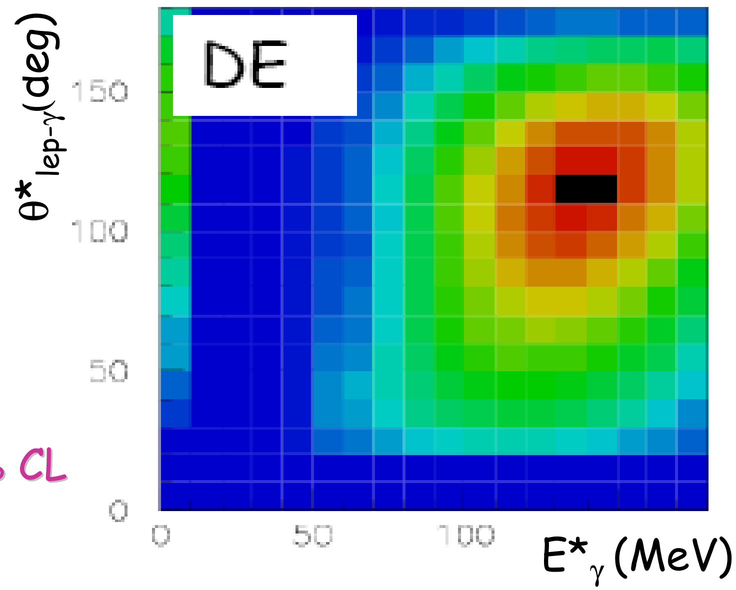
fit of the DE contribution

(-43 ± 41)

[5042 IB events]

$UL(BR_{DE}) = 2.5\times10^{-5}$ @ 90% CL

MC: DE contribution



$K_{L\mu3}$ form factor slope λ_0

it is relevant for V_{us} , to test e/μ universality with KLOE only

- K_L tagged by $K_S \to \pi^+\pi^-$
- preselection cuts : veto on $\pi^+\pi^-$ $\sqrt{(E_{miss}(\pi,\pi)^2 + p^2_{miss})} > 10 MeV$

  veto on $\pi^+\pi^-\pi^0$ $E_{miss}(\pi,\pi)^2 - p^2_{miss} - m^2_{\pi^0} > 10^{-3} MeV^2$

  veto on K_{e3} $\min(|\delta_1|,|\delta_2|) > 10 MeV$

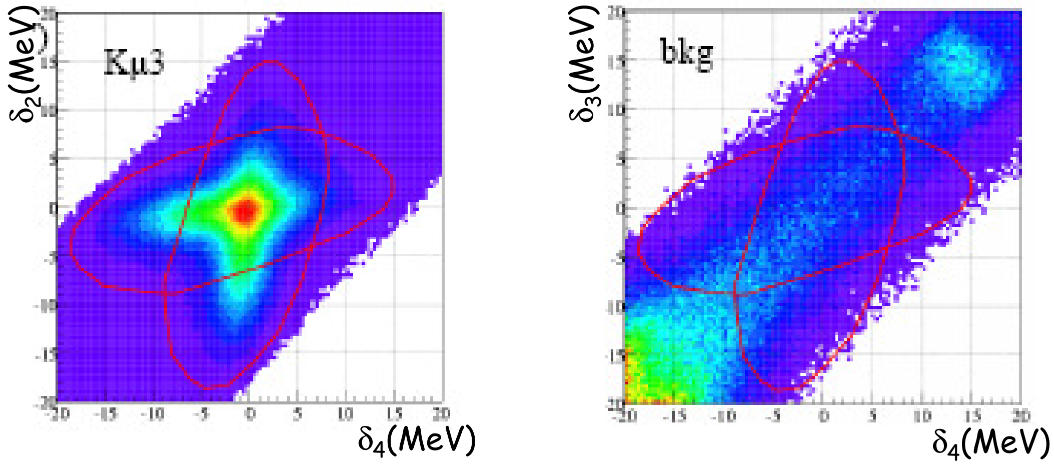
  $(\delta_1 = E_{miss}(\pi^+,e^-) - p_{miss}, \delta_2 = E_{miss}(\pi^-,e^+) - p_{miss})$

- further cut on

  $\delta_3 = E_{miss}(\pi^+,\mu^-) - p_{miss}$

  $\delta_4 = E_{miss}(\pi^-,\mu^+) - p_{miss}$

4% contamination

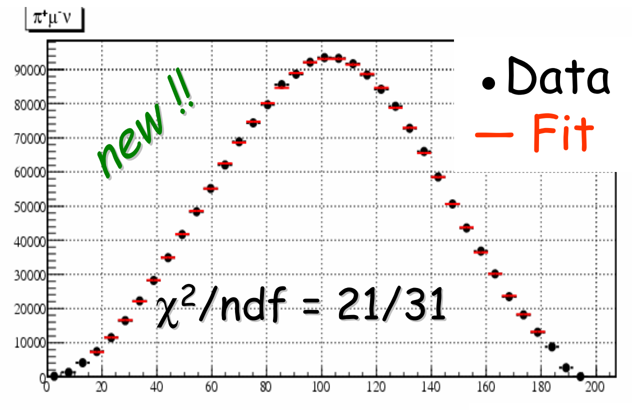


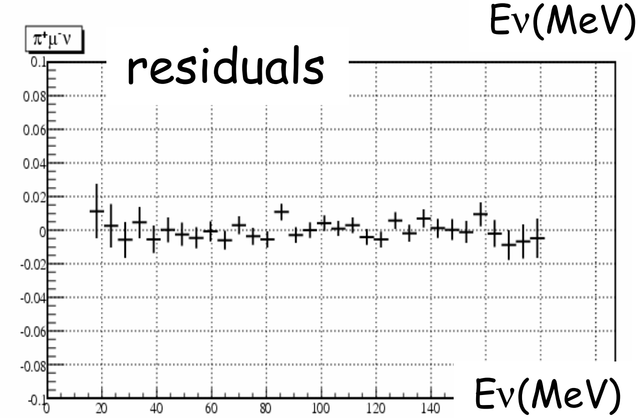
- background contamination reduced to $\cong$ 1.5% using NN trained with TOF measurements

$K_{L\mu3}$ form factor slope λ_0

π/μ separation at low energies is difficult ➔

f_0 form factor slope by fitting the E_ν distribution, combined fit with K_Le3





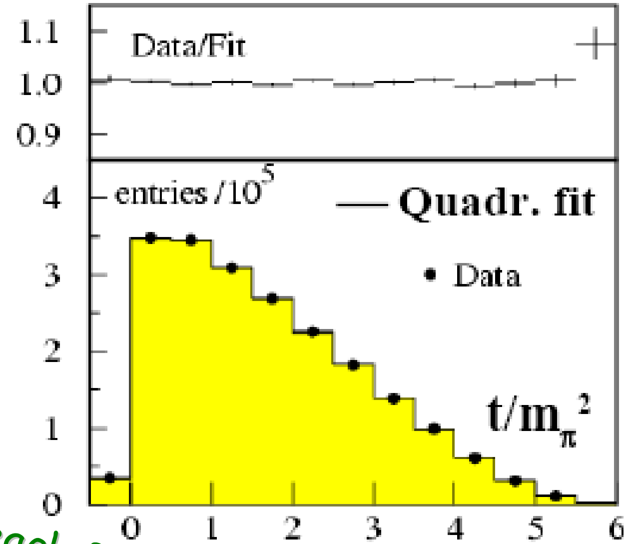
$\lambda'_+ = (25.6 \pm 1.8) \times 10^{-3}$

$\lambda''_+ = (1.44 \pm 0.79) \times 10^{-3}$

correlation matrix

λ'_+	λ''_+	λ_0
1	-0.95	0.31
X	1	-0.41
X	X	1

[PLB 636 (2006) 166]



will reach $\delta\lambda_0/\lambda_0 \sim$ 5-10% with 2.5 fb^{-1}

KLOE preliminary

$$\lambda_0 = (15.6 \pm 1.8_{stat} \pm 1.9_{syst}) \times 10^{-3}$$

KTeV *PRD 70(2004)* $\lambda_0 = (12.8 \pm 1.8) \times 10^{-3}$

NA48 *preliminary* $\lambda_0 = (9.1 \pm 1.4) \times 10^{-3}$

ISTRA+ *PLB 589(2004)* $\lambda_0 = (17.1 \pm 2.2) \times 10^{-3}$

$V_{us}f_{+}(0)$ & V_{us}/V_{ud} from KLOE

V_{us} from semileptonic kaon decays

$$\Gamma(K \rightarrow \pi l \nu(\gamma)) = |V_{us}|^2 \, |f_+^{K\pi}(0)|^2 \, \frac{G_F^2 m_K^5}{128\,\pi^3} \, S_{ew} \, C_K^2 \, I_K^l(\lambda'_+, \lambda''_+, \lambda_0) \, (1 + \delta_K^l)$$

theoretical inputs

✓ $f_+(0)$ form factor at zero momentum transfer ➔ purely theoretical calculation, presently known @ 0.8 % level (χPT, lattice)

✓ δ^l_K e.m. and isospin-breaking corrections, presently known @ few ‰ level

✓ S_{EW} universal short distance electroweak correction (1.0232), $C_K = 1$ ($2^{-1/2}$) for K^0 ($K^\pm$) decays

experimental inputs

✓ $I^l_K(\lambda'_+,\lambda''_+,\lambda_0)$ phase space integral, $\lambda'_+,\lambda''_+,\lambda_0$, denote the t-dependence of vector and scalar form factors

✓ $\Gamma K_{l3(\gamma)}$ semileptonic decay widths, evaluated from γ-inclusive BR's and lifetimes

✓ m_K appropriate kaon mass

KLOE is measuring all the relevant inputs: BR's, lifetimes, ff's

$V_{us} f_+(0)$ from KLOE results

KLOE final | *KLOE preliminary*

	$K_L e3$	$K_L \mu 3$	$K_S e3$	$K^\pm e3$	$K^\pm \mu 3$
BR	0.4008(15)	0.2699(15)	$7.046(91)\times10^{-4}$	0.05047(92)	0.03310(81)
τ	50.84(23) ns		89.58(5) ps	12.367(78) ns	

Slopes

$\lambda'_+ = 0.0256(18)$

$\lambda''_+ = 0.0014(8)$

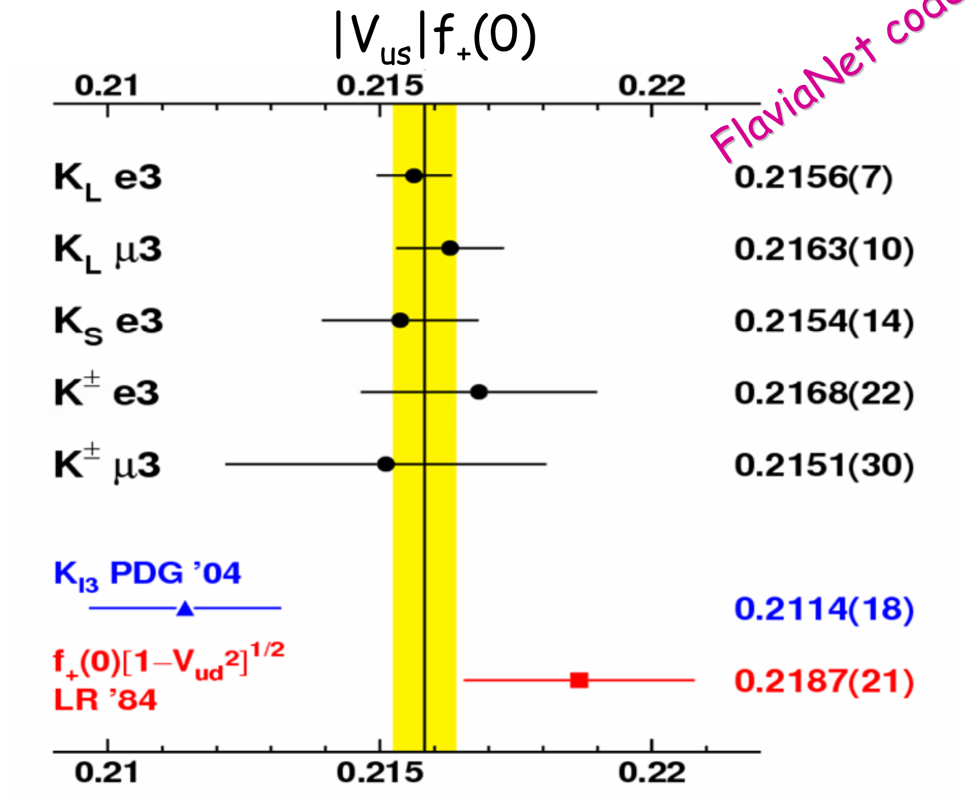
KLOE final

$\lambda_0 = 0.0156(26)$

KLOE preliminary

using $f_+(0) = 0.961(8)$, $V_{ud} = 0.97377(27)$

$\Delta = 1 - V_{ud}^2 - V_{us}^2 = (-13\pm10)\times10^{-4}$



From unitarity

- $f_+(0)=0.961(8)$
  Leutwyler and Roos Z. [Phys. **C25**, 91, 1984]
- $V_{ud}=0.97377(27)$
  Marciano and Sirlin [Phys.Rev.Lett.96 032002,2006]

$$V_{us}\times f_+(0) = 0.2187(21)$$

e/μ universality

K^0 $[G_F(\mu)/G_F(e)]^2 = 1.0065(98)$
cfr with PDG04 1.047(14)

$K^\pm$ $[G_F(\mu)/G_F(e)]^2 = 0.9843(251)$
cfr with PDG04 1.004(16)

$$\langle V_{us}\times f_+(0)\rangle_{\text{KLOE AV.}} = 0.21582(58)$$

V_{us} - V_{ud} plane

- get $|V_{us}/V_{ud}|$ from $K,\pi \to \mu\nu$ widths:

$$\frac{\Gamma(K \to \mu\nu(\gamma))}{\Gamma(\pi \to \mu\nu(\gamma))} \propto \left|\frac{V_{us}}{V_{ud}}\right|^2 \times \frac{f_K^2}{f_\pi^2}$$

(Marciano PRL93 231803,2004)

- from the KLOE analysis of 175 pb^{-1}
  $BR(K^+ \to \mu^+\nu(\gamma)) = 63.66(9)(15)\%$

- from lattice [MILC Coll. 2006]
  $f_K/f_\pi = 1.208(2)(^{+7}_{-14})$

Inputs

$V_{us}/V_{ud} = 0.2286(^{+27}_{-15})$

$V_{us} = 0.2246(20)$

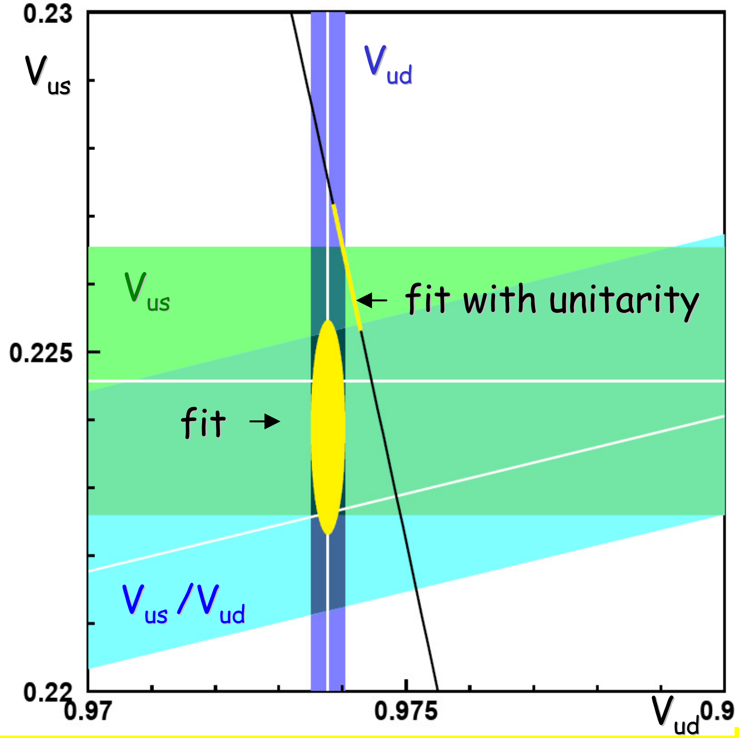
K_{l3} KLOE, using $f_+(0)=0.961(8)$

$V_{ud} = 0.97377(27)$

Marciano and Sirlin
Phys.Rev.Lett.96 032002,2006

Fit results, no constraint

$\chi^2/ndf = 0.35/1$
$P(\chi^2) = 0.56$
$V_{us} = 0.2239(16)$
$V_{ud} = 0.97377(27)$



$\Delta = 1 - V_{ud}^2 - V_{us}^2 = (1.6 \pm 1.2) \times 10^{-3}$

Fit results, unitarity constraint
$\chi^2/ndf = 3.74/2$, $P(\chi^2) = 0.15$, $V_{us} = 0.2262(9)$, $V_{ud} = 0.97407(22)$

$V_{us}f_+(0)$ from world data

the *FlaviaNet Kaon WG* performs fits to world data on the BRs and lifetime for the K_L, K_S, $K^\pm$ with the constraint that the BRs sum to unity *(presented at CKM-Nagoya)*

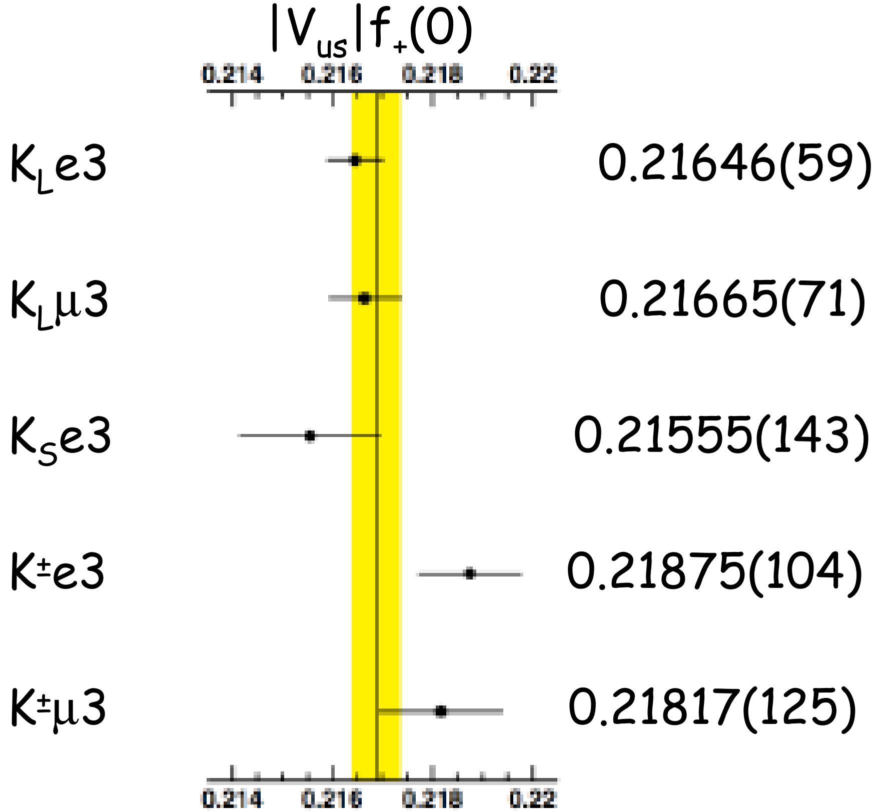
Slopes

$\lambda'_+ = 0.02492(83)$
$\lambda''_+ = 0.00159(36)$
$\lambda_0 = 0.01607(82)$

(KLOE, KTeV, NA48 and Istra+ ave.)

using $f_+(0) = 0.961(8)$, $V_{ud} = 0.97377(27)$

$\Delta = 1 - V_{ud}^2 - V_{us}^2 = (0.8 \pm 1.4) \times 10^{-3}$



not possible to fit to only new $K^\pm$ data (unlike for K_L)

- ✓ only $K^\pm_{l3}$ and $K^\pm_{l3}/\pi\pi^0$ have been measured recently
- ✓ $K^\pm_{l3}$ and $\pi\pi^0$ highly correlated in fit
- ✓ new measurement of $\pi\pi^0$ is crucial

$\langle V_{us} \times f_+(0) \rangle_{\text{WORD AV.}} = 0.21686(49)$

Conclusions

KLOE has obtained new preliminary results on

- $BR(K_S \to e^+e^-)$
- $BR(K_S \to \gamma\gamma)$
- $BR(K_L \to e\pi\nu\gamma)$
- $K_{L\mu3}$ form factor slope λ_0

recent KLOE measurements greatly improve knowledge of V_{us}

- the CKM matrix appears to be unitary within ~ 1σ
- V_{us} still only known to about 1%

forthcoming developments

- final results on $K^{\pm}_{l3}$ branching ratios and $K^{\pm}$ lifetime
- completion of the $BR(K^+ \to \pi^+\pi^0)$ measurement

perspectives with 2.5 fb^{-1} of collected data

- more and better measurements of form-factor slopes (K_{e3} and $K_{\mu3}$)
- improve K_L and $K^{\pm}$ lifetimes
- fractional accuracy of < 1% on the BR for $K_S \to \pi e\nu$ and for $K^{\pm}_{\ell3}$

What's next ? KLOE2

A new scheme to increase DAΦNE luminosity by a factor O(5) has been proposed by P.Raimondi (***crabbed waist collisions***) – test in autumn 2007

If successful a new round of measurements with an improved KLOE detector could start in 2009

*The KLOE detector has proven to well face the challenge, nevertheless **something can be improved**:*

- add an **inner tracker**
- add a **tagging system** for $e^+e^- \rightarrow e^+e^-\gamma\gamma$
- increase the **EMC read-out granularity**
- update / upgrade **the data acquisition**

What's next ? KLOE2

- **Time evolution of entangled kaon states**, reach the sensitivity to the Planck scale: tests of CPT-symmetry and quantum mechanics
- **e–μ universality** ($K \rightarrow e\nu$ / $K \rightarrow \mu\nu$) and the **mass of the muon neutrino**
- **universality of the weak coupling** to leptons and quarks, CKM matrix unitarity
- **rare K_S decays** (semileptonic charge asymmetry, $K_S \rightarrow \pi^+\pi^-\pi^0$, $K_S \rightarrow \pi^0\pi^0\pi^0$)
- **light mesons**: structure of scalars (via $\gamma\gamma$ interaction), η and η' physics
- **$\sigma(e^+e^- \rightarrow$ hadrons)**, muon anomaly, evolution of α_{em}
- **baryon electromagnetic form factors**, $e^+e^- \rightarrow pp$, nn, $\Lambda\Lambda$
- *… and more*

a new exciting challenge!
who wants to join us is welcome !!!

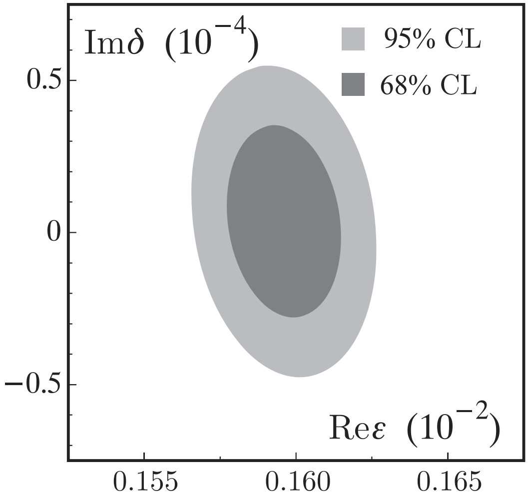
Spare slides

CPT test: the Bell-Steinberger relation

K_S K_L observables can be used for the CPT test from unitarity

$$(1 + i \tan \phi_{SW}) [\mathrm{Re}\,\varepsilon - i\,\mathrm{Im}\,\delta] = \frac{1}{\Gamma_S} \sum_f A^*(K_S \to f)\, A(K_L \to f) = \sum_f \alpha_f$$

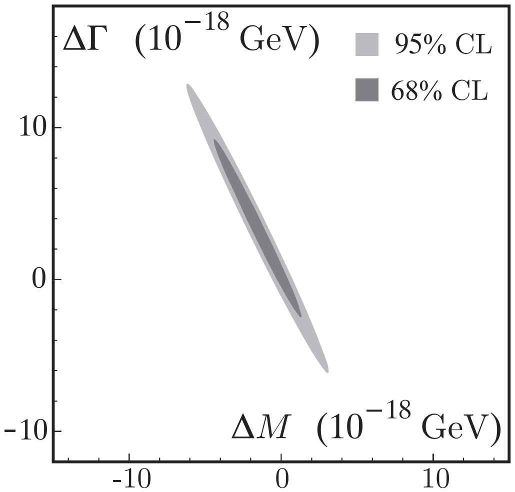
JHEP12(2006) 011



Re ε = (159.6 ± 1.3) ×10^{-5}.
Im δ = (0.4 ± 2.1) × 10^{-5}

the main contribution to the uncertainty now comes from η_{+-}

CPLEAR
Re ε = (164.9 ± 2.5)X10^{-5}.
Im δ = (2.4 ± 5.0)X10^{-5}



$$\Delta\Gamma = \Gamma\left(K^0\right) - \Gamma\left(\overline{K}^0\right)$$

$$\Delta M = M\left(K^0\right) - M\left(\overline{K}^0\right)$$

$$\delta = \frac{1}{2} \frac{\Delta M - \frac{i}{2}\Delta\Gamma}{(M_L - M_S) + \frac{i}{2}(\Gamma_S - \Gamma_L)}$$

Assuming ΔΓ= 0, i.e. no CPT viol. in decay:
(-5.3 ×10^{-19} < ΔM < 6.3 ×10^{-19}) GeV at 95% C.L.

$\phi \to K_S K_L \to \pi^+\pi^-\pi^+\pi^-$: test of quantum coherence

$$I\left(\pi^+\pi^-,\pi^+\pi^-;|\Delta t|\right) \propto \left\{e^{-\Gamma_L|\Delta t|} + e^{-\Gamma_S|\Delta t|} - 2\cdot\left(1-\zeta_{SL}\right)\cdot e^{-(\Gamma_S+\Gamma_L)|\Delta t|/2}\cos\left(\Delta m|\Delta t|\right)\right\}$$

- Fit including Δt resolution and efficiency effects + regeneration
- Γ_S, Γ_L Δm fixed from PDG

Decoherence parameter:

$\zeta_{SL} = 0 \quad \to \quad$ QM

$\zeta_{SL} = 1 \quad \to \quad$ total decoherence

PLB 642(2006) 315

KLOE result :

$$\zeta_{SL} = 0.018 \pm 0.040_{\text{STAT}} \pm 0.007_{\text{SYST}}$$

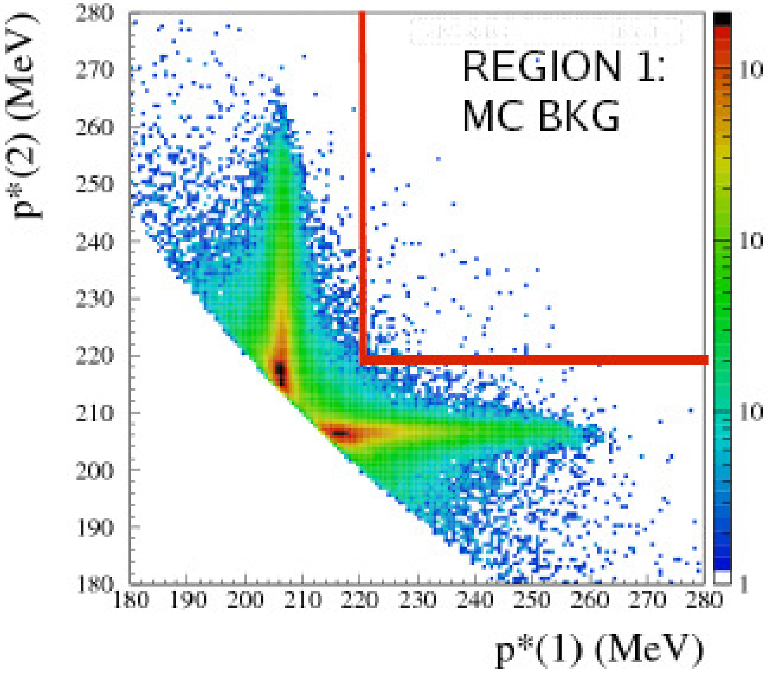
$$\zeta_{SL} < 0.098 \quad \text{at} \;\; 95\% \text{ C.L.}$$

→ *with 2.5 fb^{-1} :* $\pm 0.015_{\text{STAT}}$

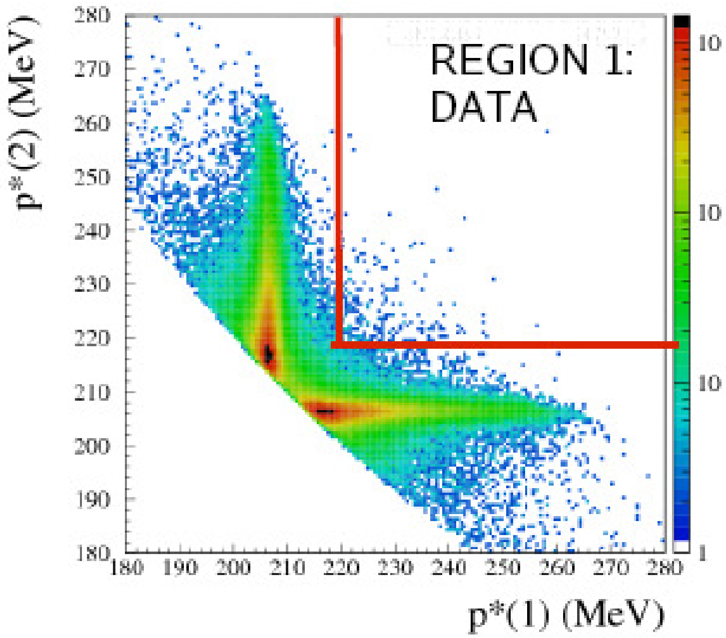
From CPLEAR data, Bertlmann et al. (PR D60 (1999) 114032) obtain :

$$\zeta_{SL} = 0.13 \pm 0.16$$

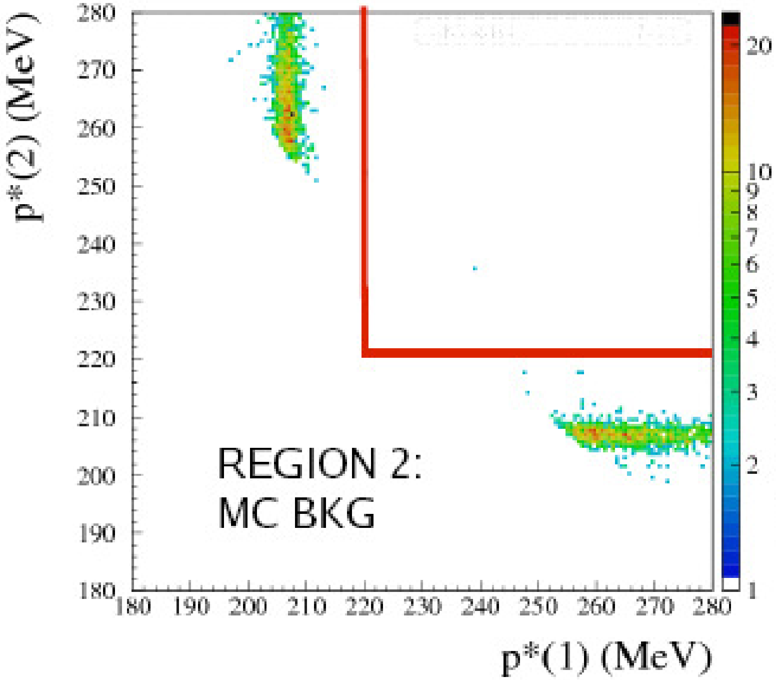
Bkg rejection cuts p^*_π



Distribution of track momenta in K_S rest frame (pion hypothesis) shows that, for most of $\pi^+\pi^-$ and $\pi\mu$ bkg events, momentum of one pion is well reconstructed



Bkg rejection cuts p^*_π

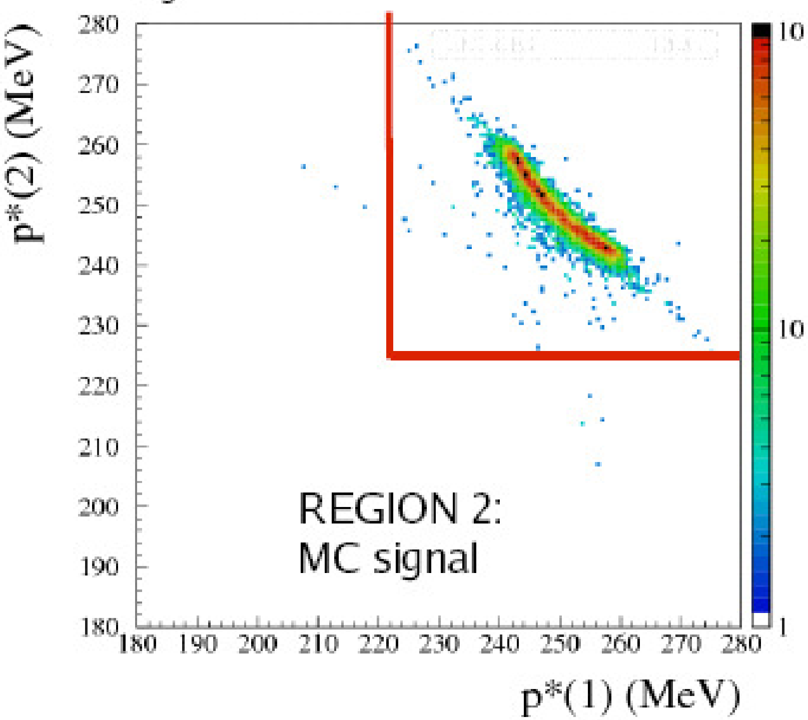


The same behavior is observed in **REGION 2** (where signal is!). Require for both tracks:

$$p^*_\pi \geq 220 \text{ MeV}$$

$\varepsilon_{\pi\pi,\pi\mu} = 0.014$

$\varepsilon_{sig} = 0.962$



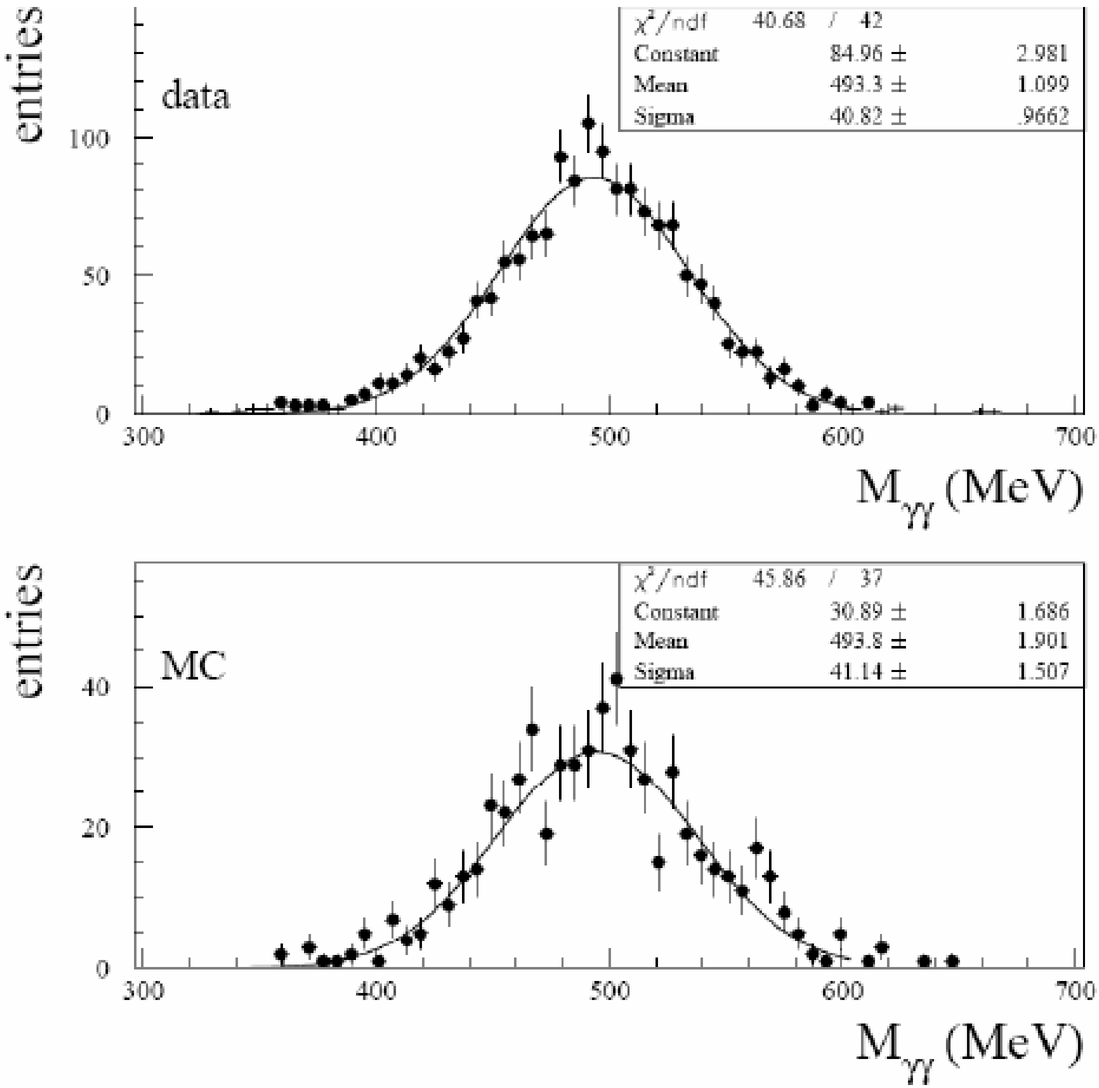
Analysis of $K_S \to \gamma\gamma$

- $K_L \to \gamma\gamma$ control sample selected to check the energy scale on data-MC

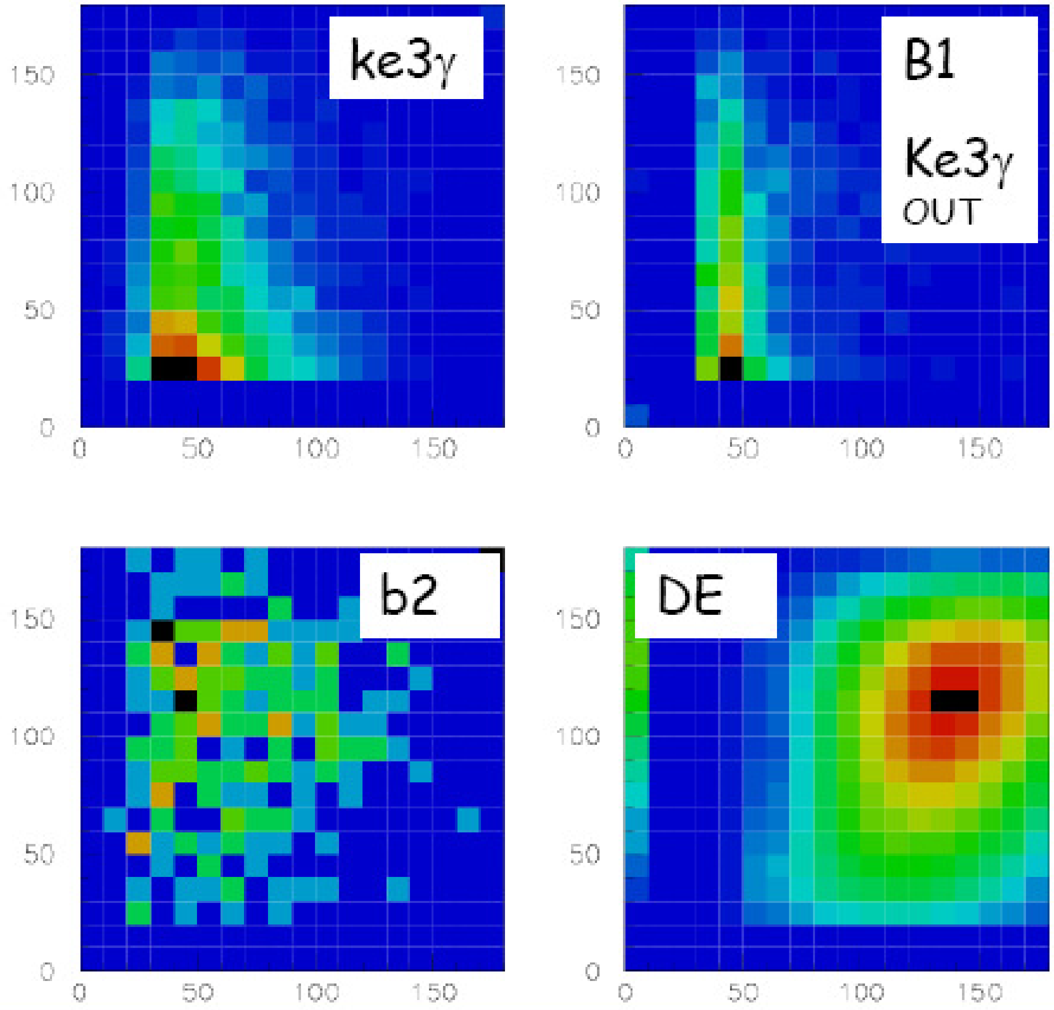
$K_L \to \gamma\gamma$ sample obtained using an analysis based on $\chi 2_{fit} + \theta_{\gamma\gamma}$ cut

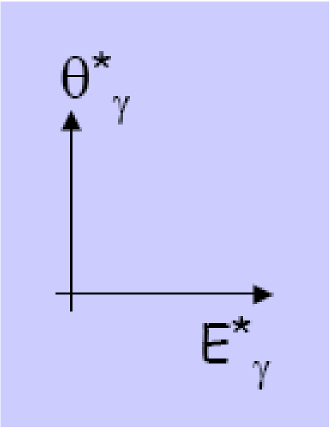
DATA = 60 pb^{-1}
MC = 35 pb^{-1}

After scale calibration



Analysis of $K_L \rightarrow \pi e \nu \gamma$





P. de Simone 8/03/2007 - LaThuile

V_{us} $f_+(0)$ from KLOE results

KLOE final — *KLOE preliminary*

	K_L e3	K_L μ3	K_S e3	$K^\pm$ e3	$K^\pm$ μ3
BR	0.4008(15)	0.2699(15)	7.046(91)×10^{-4}	0.05047(92)	0.03310(81)
τ	50.84(23) ns		89.58(5) ps	12.367(78) ns	

Slopes

$\lambda'_+ = 0.0256(18)$

$\lambda''_+ = 0.0014(8)$ *KLOE final*

$\lambda_0 = 0.0156(26)$ *KLOE preliminary*

FlaviaNet code

Mode	$\lvert V_{us}\rvert f^+(0)$	error %
K_Le3	0.21563(69)	0.32
K_Lμ3	0.21629(99)	0.46
K_Se3	0.21537(144)	0.67
K^+e3	0.21682(217)	1.00
K^+μ3	0.21511(295)	1.37

$$\langle V_{us}\times f_+(0)\rangle_{\text{KLOE AV.}} = 0.21582(58)$$

using $f_+(0) = 0.961(8)$, $V_{ud} = 0.97377(27)$

$\Delta = 1 - V_{ud}^2 - V_{us}^2 = (-13\pm10)\times10^{-4}$

From unitarity

- $f_+(0)$=0.961(8)
  Leutwyler and Roos Z. [Phys. **C25**, 91, 1984]
- V_{ud}=0.97377(27)
  Marciano and Sirlin [Phys.Rev.Lett.96 032002,2006]

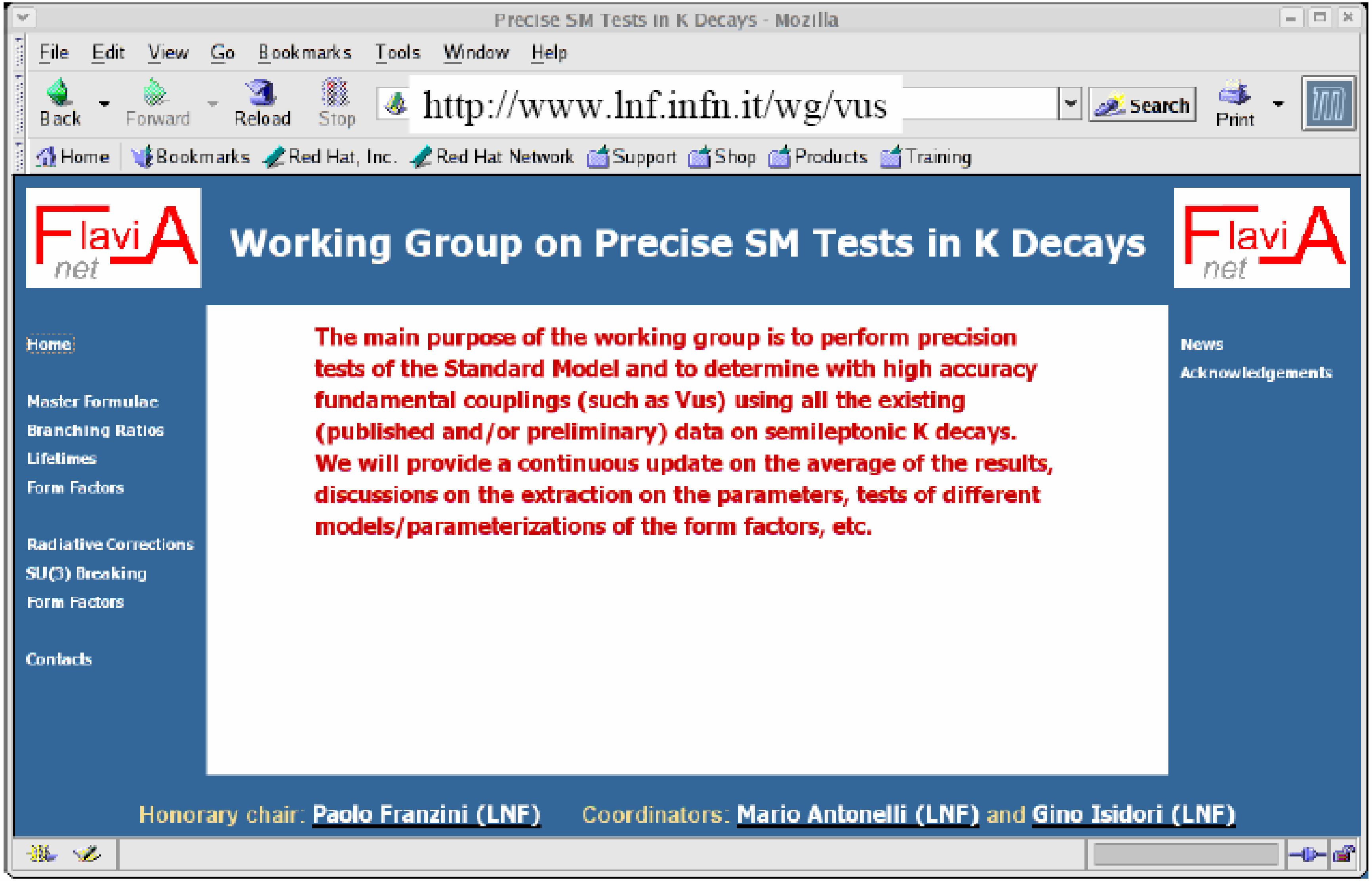
$$\mathbf{V_{us}\times f_+(0) = 0.2187(21)}$$

e/μ universality

K^0 $[G_F(\mu)/G_F(e)]^2$ = 1.0065(98) cfr with PDG04 1.047(14)

$K^\pm$ $[G_F(\mu)/G_F(e)]^2$ = 0.9843(251) cfr with PDG04 1.004(16)

A WG for kaon physics



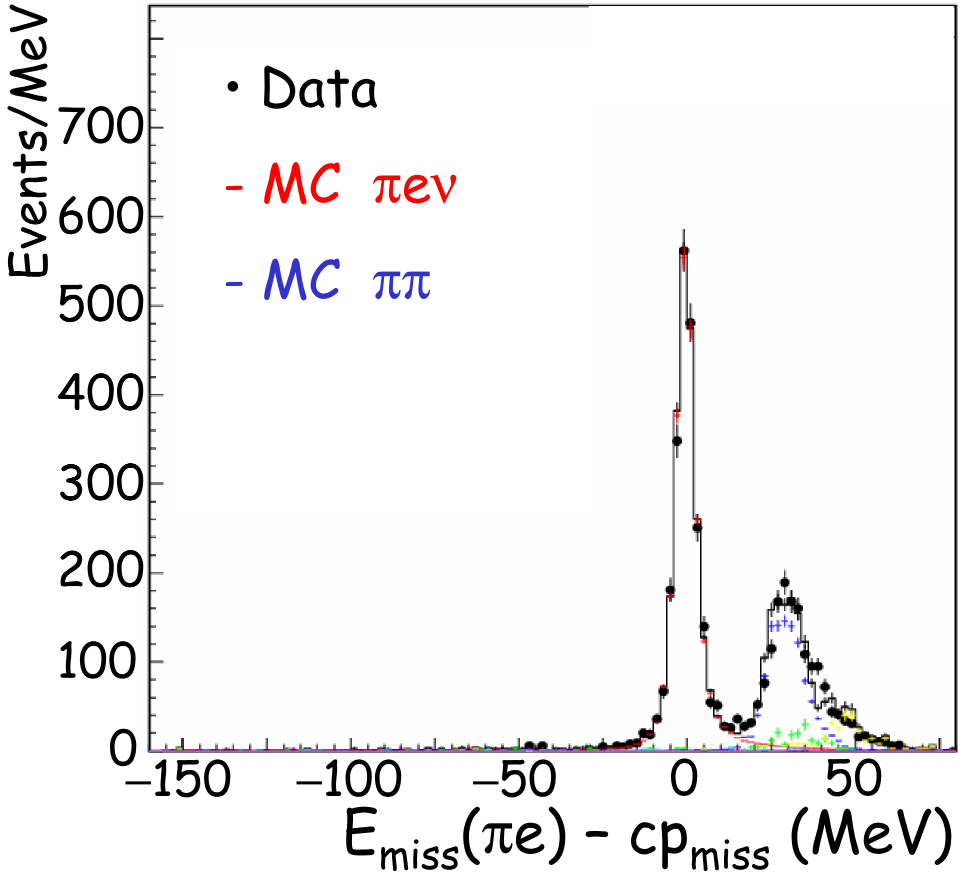
Analysis of $K_S \to \pi e \nu$

event selection (410 pb^{-1})

- K_S tagged by K_L crash
- two tracks from IP to EmC
- kinematic cuts to reject background from $K_S \to \pi\pi$
- track-cluster association required

e/π ID from TOF identifies charge of final state

number of signal counts by fitting data to a linear combination of MC spectra for signal and background (MC includes radiative processes)



normalize signal counts to $K_S \to \pi\pi(\gamma)$ counts in the same data set (use PDG04 for $BR(K_S \to \pi\pi(\gamma))$, dominated by KLOE measurement)

$K_S \to \pi e \nu$ - results

unique to KLOE

[PLB 636(2006)]

$BR(K_S \to \pi^- e^+ \nu) = (3.528 \pm 0.057 \pm 0.027) \times 10^{-4}$

$BR(K_S \to \pi^+ e^- \nu) = (3.517 \pm 0.051 \pm 0.029) \times 10^{-4}$

$BR(K_S \to \pi e \nu) = (7.046 \pm 0.077 \pm 0.049) \times 10^{-4}$

$BR(\pi e \nu)$ [KLOE '02, *Phys.Lett.B535*, 17 pb^{-1}]: $(6.91 \pm 0.34_{stat} \pm 0.15_{syst})\ 10^{-4}$

$A_S = (1.5 \pm 9.6_{stat} \pm 2.9_{syst}) \times 10^{-3}$
with 2.5 fb^{-1} KLOE can measure
A_S to 3×10^{-3}

compare to results for A_L:
KTeV $(3.322 \pm 0.058 \pm 0.047) \times 10^{-3}$
NA48 $(3.317 \pm 0.070 \pm 0.072) \times 10^{-3}$

linear form factor slope $\lambda_+ = (33.9 \pm 4.1) \times 10^{-3}$

compatible with the linear slope obtained from K_L semileptonic decays

Dominant K_L branching ratios

Absolute BR measurements to 0.5-1%

from 328 pb^{-1} data sample

K_L tagged by $K_S \to \pi^+\pi^-$:

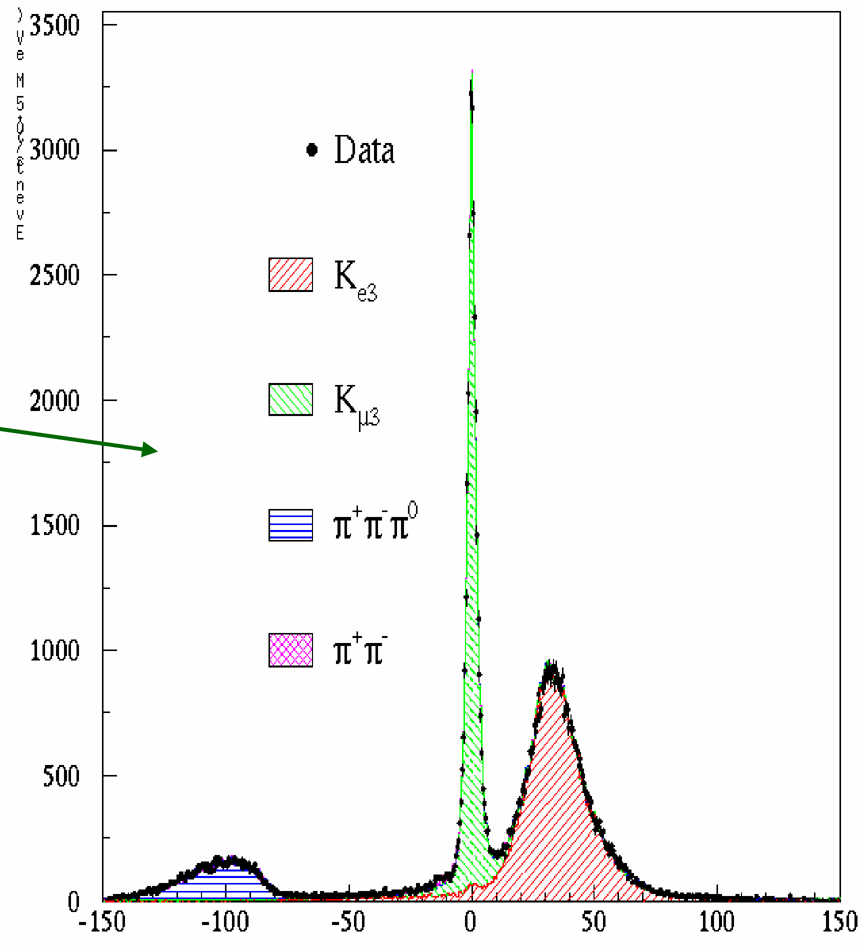
- 13×10^6 for the measurement
- 4×10^6 used to evaluate efficiencies

BR's to $\pi e\nu$, $\pi\mu\nu$, and $\pi^+\pi^-\pi^0$:

- K_L vertex reconstructed in DC
- PID using decay kinematics
- fit with MC spectra including radiative processes

BR to $\pi^0\pi^0\pi^0$:

- photon vertex reconstructed by TOF using EmC (3 clusters)
- ε_{rec} = 99%, background < 1%



Lesser of p_{miss}–E_{miss} in $\pi\mu$ or $\mu\pi$ hyp. (MeV)

Dominant K_L BRs and K_L lifetime

using the constraint $\sum BR(K_L) = 1$ we get

$BR(K_L \to \pi e \nu(\gamma)) = 0.4007 \pm 0.0006_{stat} \pm 0.0014_{syst}$

$BR(K_L \to \pi \mu \nu(\gamma)) = 0.2698 \pm 0.0006_{stat} \pm 0.0014_{syst}$

$BR(K_L \to 3\pi^0) = 0.1997 \pm 0.0005_{stat} \pm 0.0019_{syst}$

$BR(K_L \to \pi^+\pi^-\pi^0(\gamma)) = 0.1263 \pm 0.0005_{stat} \pm 0.0011_{syst}$

lifetime measurement

$\tau_L = 50.72 \pm 0.17 \pm 0.33$ ns

[PLB 632 (2006)]

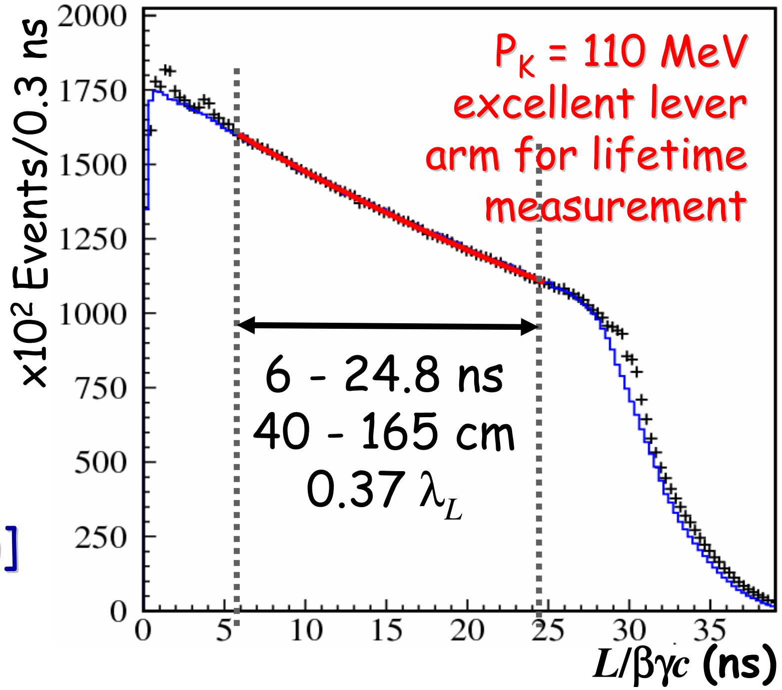
τ_L measurement from $K_L \to \pi^0\pi^0\pi^0$, 400 pb^{-1}

- require ≥ 3 γ's
- $\varepsilon(L_K) \sim 99\%$, uniform in L
- $\sigma_L(\gamma\gamma) \sim 2.5$ cm
- background $\sim 1.3\%$

use $K_L \to \pi^+\pi^-\pi^0$ for
- EmC time scale
- γ vertex efficiency

lifetime measurement [PLB 626 (2005)]

$\tau_L = 50.92 \pm 0.17 \pm 0.25$ ns



KLOE average $\to \tau_L = 50.84 \pm 0.23$ ns (Vosburg, '72 $\tau_L = 51.54 \pm 0.44$ ns)

K_{Le3} form factor slopes

- 328 pb^{-1}, 2×10^6 K_{e3} decays
- PID by kinematic cuts + TOF (~ 0.7% final background contamination)
- separate measurement for each charge state ($e^+\pi^-$, π^+e^-) to check systematics
- momentum transfer t measured from π and K_L momenta: $\sigma(t/m_\pi^2) \sim 0.3$

Linear: $1 + \lambda_+ t$ P(χ^2) =89%

$\lambda_+ = (28.6 \pm 0.5 \pm 0.4) \times 10^{-3}$

Quadratic: $1 + \lambda'_+ t/m^2_{\pi+} + 1/2\, \lambda''_+ (t/m^2_{\pi+})^2$

$\lambda'_+ = (25.5 \pm 1.5 \pm 1.0) \times 10^{-3}$

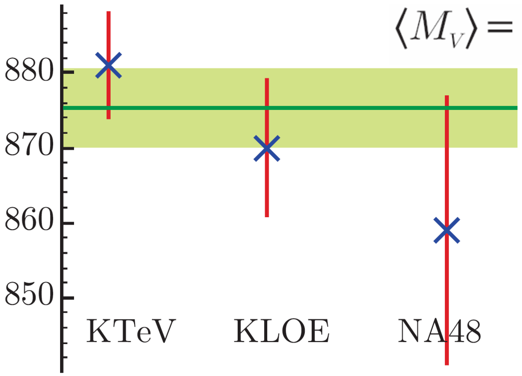
$\lambda''_+ = (1.4 \pm 0.7 \pm 0.4) \times 10^{-3}$

$\rho(\lambda'_+, \lambda''_+) = -0.95$ P(χ^2) =92%

Pole model: $M_V^2/(M_V^2 - t)$,

Taylor exp.$\Rightarrow$ $\lambda'_+ = (m_\pi/M_V)^2$, $\lambda''_+ = 2\,\lambda'^2_+$

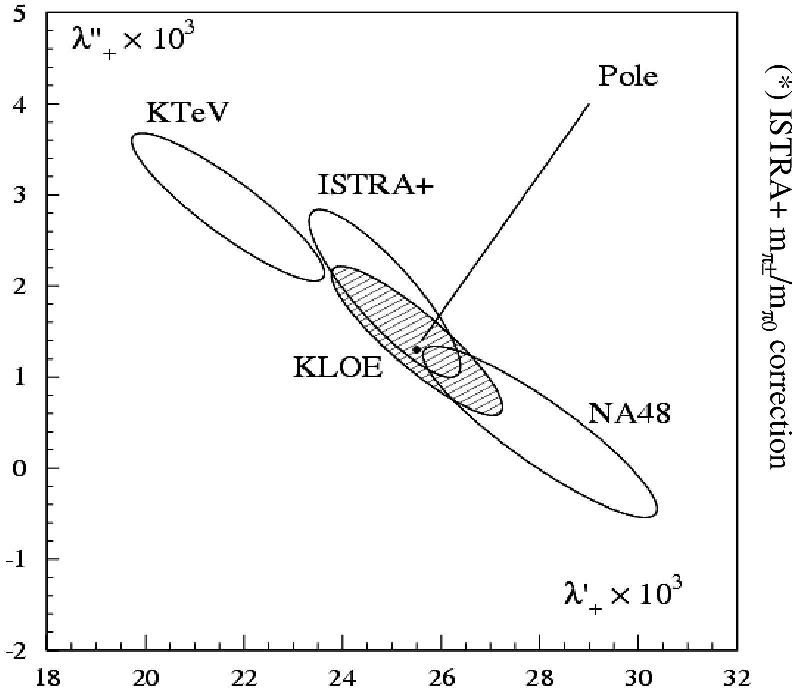
$m_V = (870 \pm 7)$ MeV P(χ^2) =92.4%



$\langle M_V \rangle = 875.3 \pm 5.4$, $\chi^2 = 1.8$

$\lambda' = 25.42 \pm 0.31$

$\lambda'' = 1.29 \pm 0.032$



[PLB 636(2006)]

Phase space integral

Pole model versus Quadratic parameterization

- KLOE: 0.5 per mil difference
- KTeV: 6 per mil difference

Measurement of the $K^{\pm}$ lifetime

- two methods to measure $\tau_{\pm}$ allow cross checks on the systematic error
- common to both methods
  - tag events with $K_{\mu 2}$ decay
  - kaon decay vertex in the DC

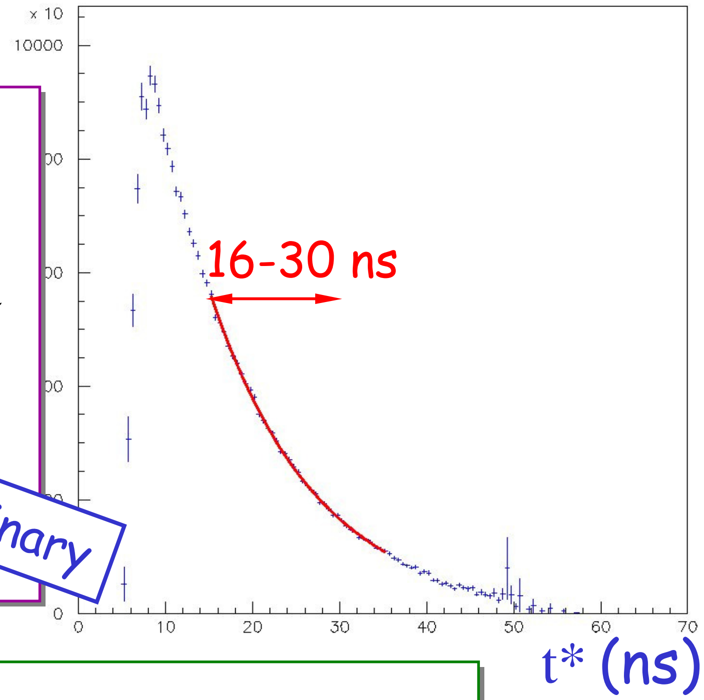
1st method: $\tau_{\pm}$ from the K decay length

Measure the kaon decay length taking into account the energy loss: $t^* = \sum_i L_i/(\beta_i \gamma_i c)$

- Efficiency and resolution functions measured on data by means of π^0 vertex reconstruction ($K \to \pi^0 X$)
- Fit of the t* distribution

$$\tau_{\pm} = 12.367 \pm 0.044_{Stat} \pm 0.065_{Syst} \text{ ns}$$

KLOE preliminary



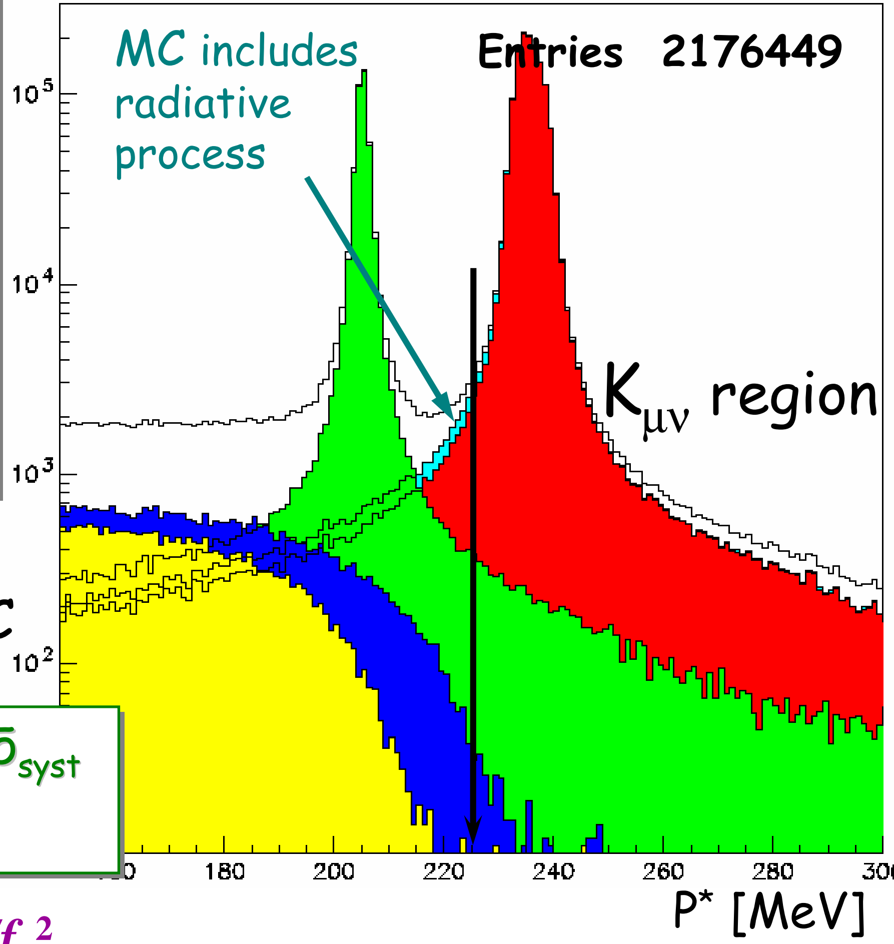
2nd method: $\tau_{\pm}$ from the K decay time

- Use $K \to \pi^0 X$ decays
- Use tag information to estimate the T_0 i.e. the $\phi \to K^+K^-$ time
- Measure the kaon proper time: $t^* = (t_\gamma - R_\gamma/c - T_0)\gamma_K$ using the γ clusters
- Lorentz factor $\boldsymbol{\gamma_K}$: slowly changing along the kaon path

Measurement of the BR ($K^+ \to \mu^+\nu(\gamma)$)

Signal selection

- tag from $K^- \to \mu^-\nu$
- 175 pb^{-1}: 1/3 used for signal selection, 2/3 used as efficiency sample
- decay vertex in DC & fill the P* spectrum
- subtraction of π^0 identified background
- count events in (225,400) MeV window of the momentum distribution in K rest frame (π hypothesis)



- selection efficiency measured on data
- radiated γ acceptance computed by MC

$BR(K^+ \to \mu^+\nu(\gamma)) = 0.6366 \pm 0.0009_{stat} \pm 0.0015_{syst}$

[PLB 632 (2006)]

- $\Gamma(K \to \mu\nu(\gamma))/\Gamma(\pi \to \mu\nu(\gamma)) \propto |V_{us}|^2/|V_{ud}|^2 f_K^2/f_\pi^2$
- From lattice calculations: $f_K/f_\pi = 1.198(3)(^{+16}_{-5})$

  (MILC Coll. PoS (LAT 2005) 025,2005)

$|V_{us}| / |V_{ud}| = 0.2294 \pm 0.0026$

Measurement of the BR($K^{\pm}_{l3}$)

- **4 independent-tag samples: $K^{+}\mu 2$, $K^{+}\pi 2$, $K^{-}\mu 2$, and $K^{-}\pi 2$**

  keep under control the systematic effects due to the tag selection
- kinematical cuts to reject non-semileptonic decays,

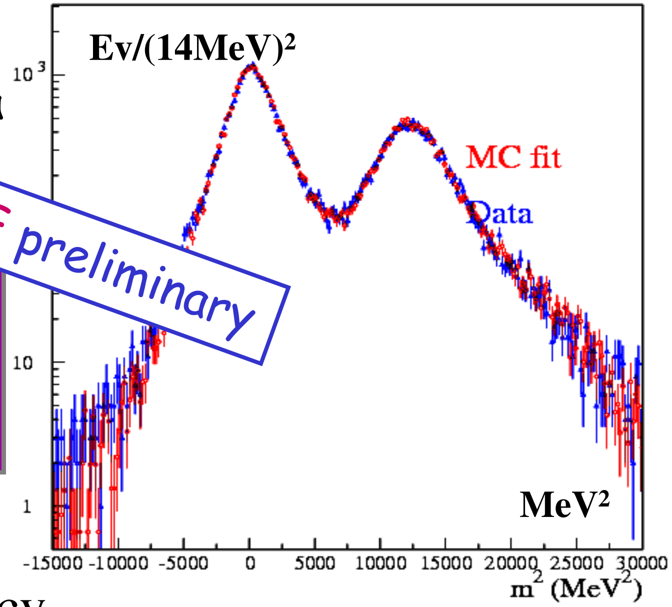
  residual background is about 1.5% of the selected $K^{\pm}l3$ sample
- **constrained likelihood fit of m^2** data distributions from **ToF** measurements

  count the number of signal events
- selection efficiency from MC and correct for Data/MC differences

perform the BR measurement on each tag sample, separately normalizing to tag counts in the same data set, and average accounting for correlations:

BR($K^{\pm}_{e3}$) =
$$(5.047 \pm 0.019_{Stat} \pm 0.039_{Syst\text{-}Stat} \pm 0.081_{Sys})\times 10^{-2}$$
BR($K^{\pm}_{\mu 3}$) =
$$(3.310 \pm 0.016_{Stat} \pm 0.045_{Syst\text{-}Stat} \pm 0.065_{Sys})\times 10^{-2}$$

KLOE preliminary



- fractional accuracy of 1.8% for Ke3, 2.4% for Kμ3
- the error is dominated by the error on Data/MC efficiency correction and the systematics due to the signal selection efficiency is under evaluation

Kaon production

the ϕ decay at rest provides monochromatic and pure kaon beams

$\sigma(e^+e^- \to \phi) \approx 3\ \mu b$

$K_S, K^+ \longleftarrow \phi \longrightarrow K_L, K^-$

detection of a K^+ (K^-) guarantees the presence of a K^- (K^+) with known momentum and direction (the same for $K_s K_L$) $\Rightarrow$ **tagging**

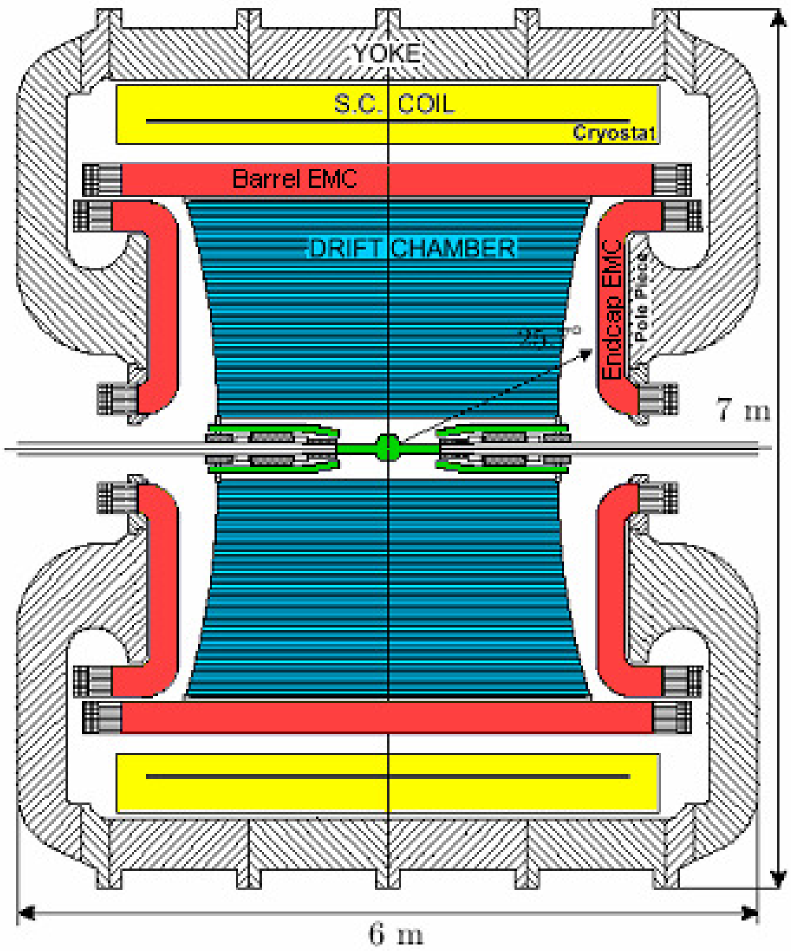
pure kaon beam obtained $\Rightarrow$ normalization (N_{tag}) sample

$\Rightarrow$ allows precision measurements of absolute BRs

BR ($\phi \to K^+K^-$) $\cong$ 49%
$P_{lab}(K^\pm)$ = 127 MeV/c
$\lambda(K^\pm) \cong$ 95 cm

BR ($\phi \to K_S K_L$) $\cong$ 34%
$p_{lab}(K_{S,L})$ = 110 MeV/c
$\lambda(K_S)$ = 0.6 cm K_S decays near interaction point
$\lambda(K_L)$ = 340 cm Large detector to keep reasonable acceptance for K_L decays ~$0.5\,\lambda(K_L)$

The KLOE experiment



Be beam pipe (0.5 mm thick), r =10 cm (K_S fiducial volume)
Instrumented permanent magnet quadrupoles (32 PMT's)

Drift chamber (4 m Ø × 3.3 m)
90% He + 10% IsoB, CF frame
12582 stereo sense wires

Electromagnetic calorimeter
Lead/scintillating fibers
4880 PMT's, cover 98% of the solid angle

Superconducting coil
B = 0.52 T ($\int$ Bdl = 2 T·m)

Tagging of K^+K^- beams

$K^\pm$ beam tagged from

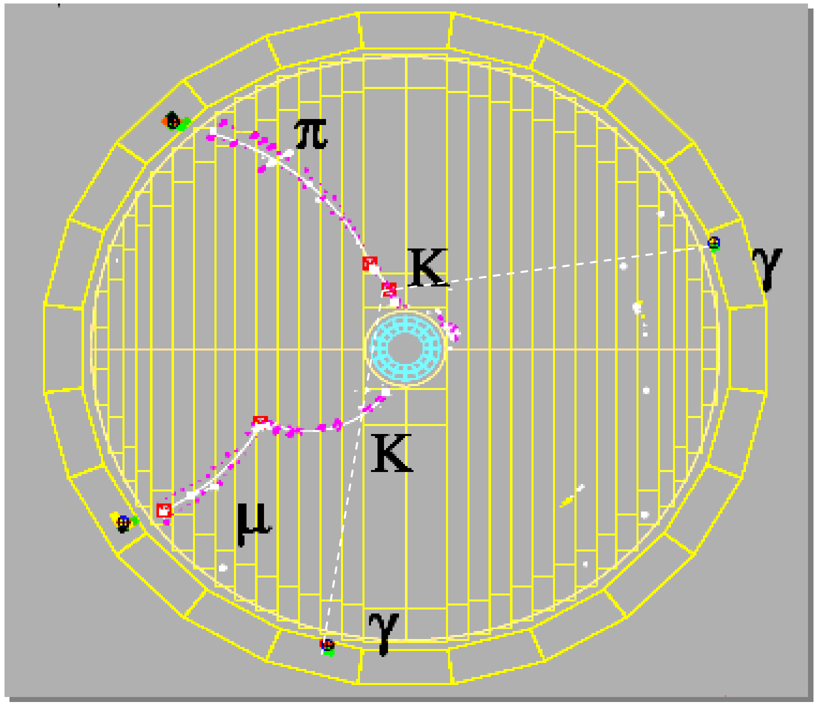
$K^\pm \to \pi^\pm\pi^0,\ \mu^\pm\nu$ (85% of $K^\pm$ decays)

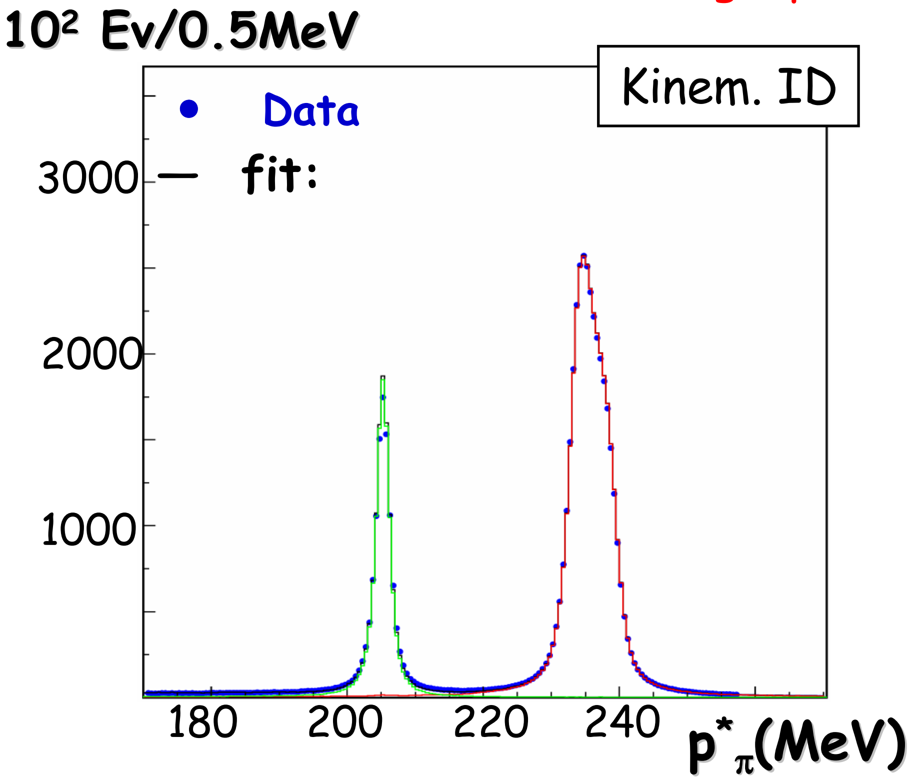
$\cong 1.5 \times 10^6\ K^+K^-$ evts/pb^{-1}

two-body decays identified as peaks in the momentum spectrum of secondary tracks in the kaon rest frame → $P^*(m_\pi)$

$\varepsilon_{tag} \cong 36\ \% \Rightarrow \cong 3.4 \times 10^5\ \mu\nu$ tags/pb^{-1}

$\cong 1.1 \times 10^5\ \pi\pi^0$ tags/pb^{-1}





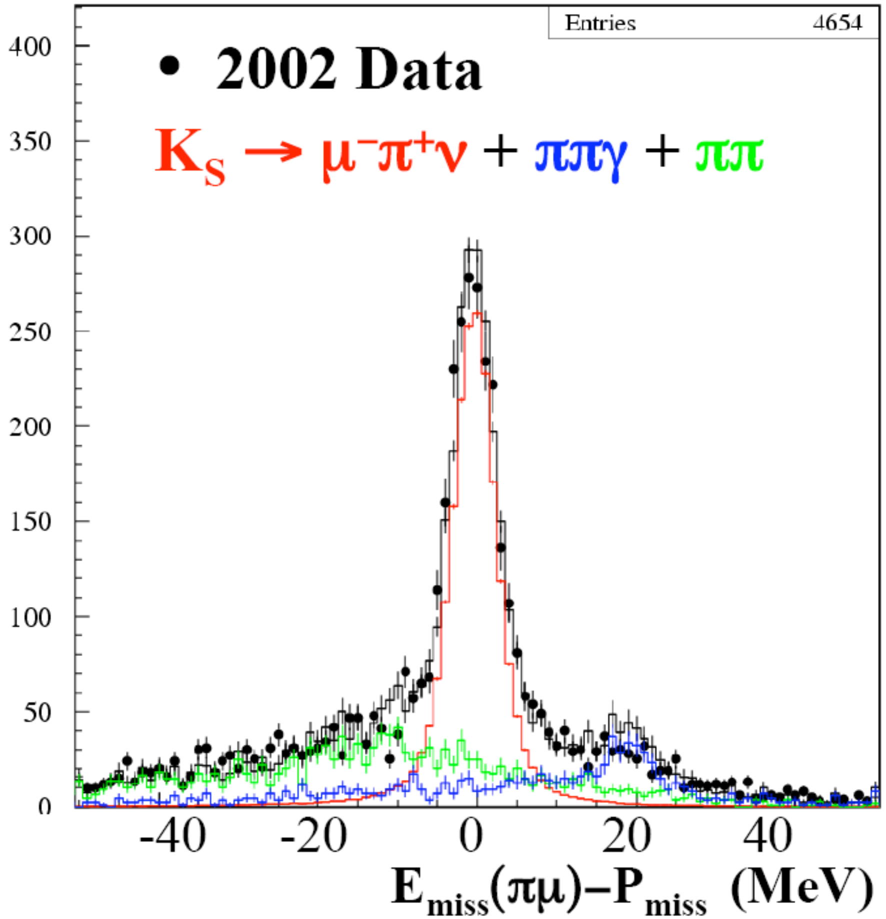
First observation of $K_S \to \pi\mu\nu$

Measurement never done before
more difficult than K_{Se3}

- lower BR: expect 4×10^{-4}
- background events from

  $K_S \to \pi\pi$, $\pi \to \mu\nu$

  same PIDs of the signal
- event counting from the fit to $E_{miss}(\pi\mu) - P_{miss}$ distribution →
  ~ 3% stat error
- efficiency estimate from $K_{L\mu3}$ early decays and from MC + data control samples



Coming soon !!

$K_L \to \pi^+\pi^-$

PLB 638(2006)140

signal selection:

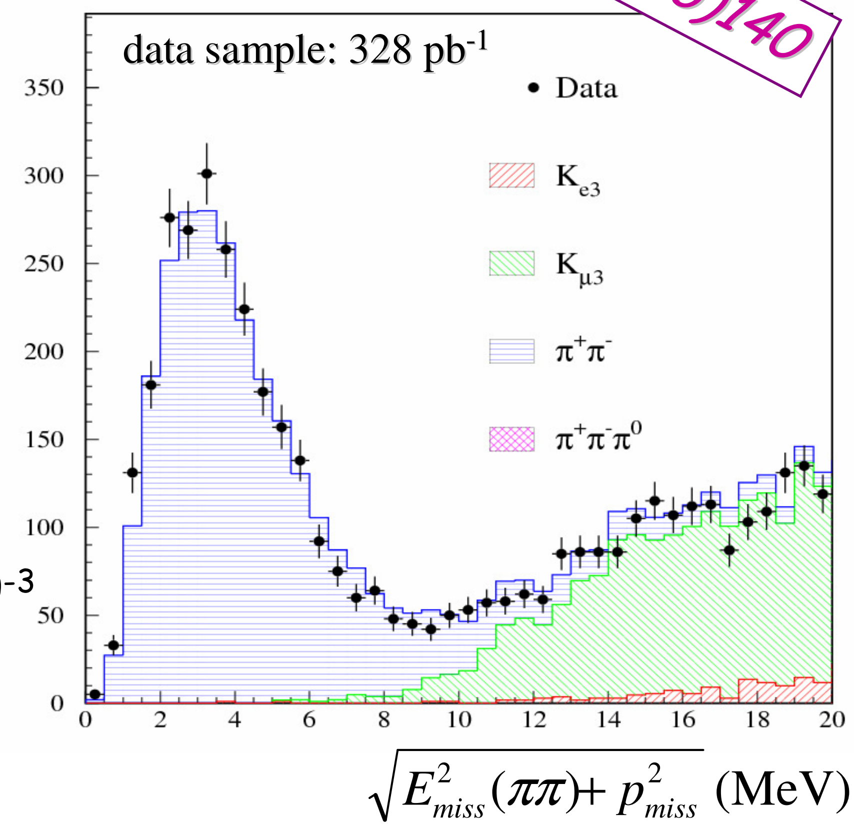
- K_L beam tagged by $K_S \to \pi^+\pi^-$
- K_L vertex reconstructed in DC
- PID using decay kinematics
- fit with MC spectra

normalization using $K_L \to \pi\mu\nu$ events in the same data set

$BR(K_L \to \pi^+\pi^-) = (1.963 \pm 0.012 \pm 0.017) \times 10^{-3}$

- agreement with KTeV = $(1.975 \pm 0.012) \times 10^{-3}$
- confirms the discrepancy with

PDG04 = $(2.080 \pm 0.025) \times 10^{-3}$



using $BR(K_S \to \pi\pi)$ and τ_L from KLOE and τ_S from PDG04

$|\varepsilon| = (2.216 \pm 0.013) \times 10^{-3}$ PDG04 $|\varepsilon| = (2.280 \pm 0.013) \times 10^{-3}$

1.6σ agreement with prediction from Unitarity Triangle

$K_{e2}/K_{\mu 2}$

- Extremely well known within SM **R_K^{SM} = (2.472±0.001)x10^{-5}**
- Probe μ-e universality: non-universal terms from LFV sources in SUSY extensions
- from NA48/2 R_K^{NA48} = (2.416±0.043$_{stat}$±0.024$_{syst}$)x10^{-5}

at KLOE the measurement is extremely challenging

i. good reconstruction eff. for signal
ii. trigger eff. ~ 1
iii. but difficult PID due to huge Kμ2 background *O(4x10^4)*

5x10^3 events/$K^\pm$ @ 2fb^{-1}

a possible μ/e discrimination strategy can rely on

- decay kinematics (good separation)
- TOF (modest separation, also muons have β ~1)
- cluster shape in ECAL (could be fairly good, *under study*)
- dE/dx in the DC (could help , *under study*)