KLOE results on kaon decays

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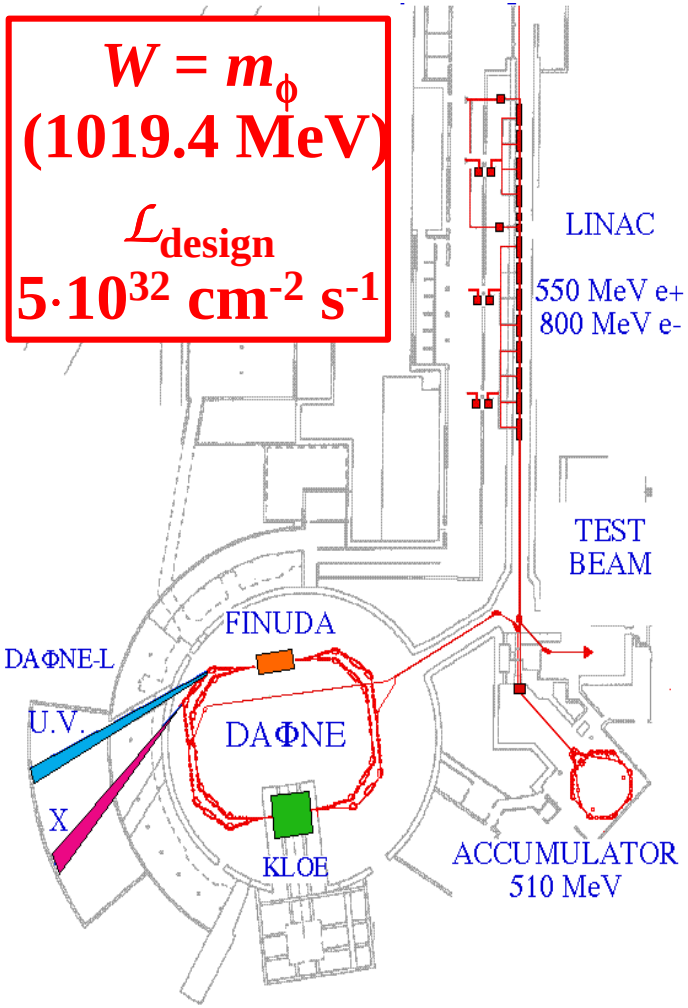
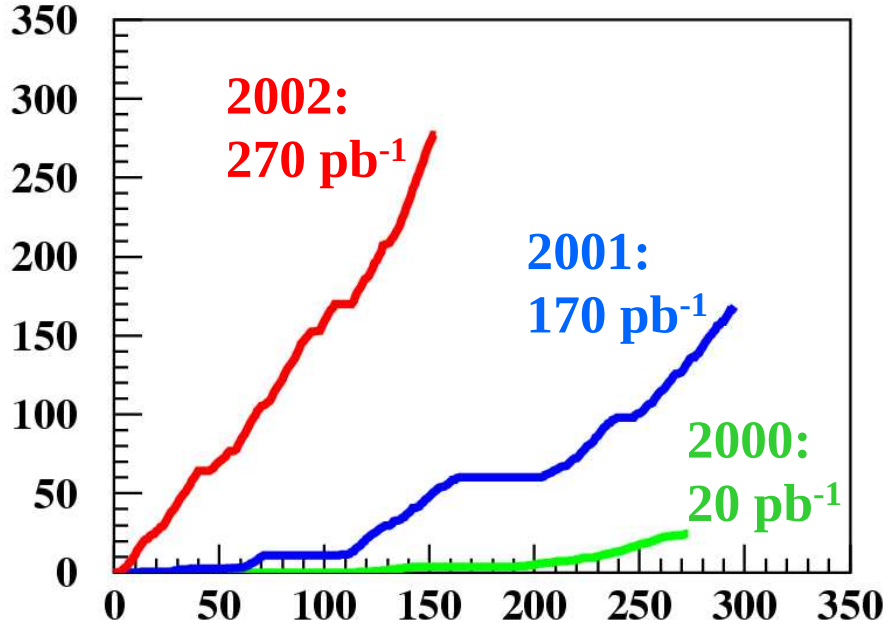
For the KLOE experiment

- **The DaΦne collider**
- **The KLOE detector**
- **Neutral kaons**
- **Measurement of K_L BR's**
- **Measurement of K_L lifetime**
- **Measurement of $Ks \rightarrow \pi e \nu$ BR**
- **Charged kaons**
- **Measurement of $K^+ \rightarrow \mu \nu (\gamma)$**
- **Semileptonic decays of $K^\pm$**
- **conclusion**

DAΦNE



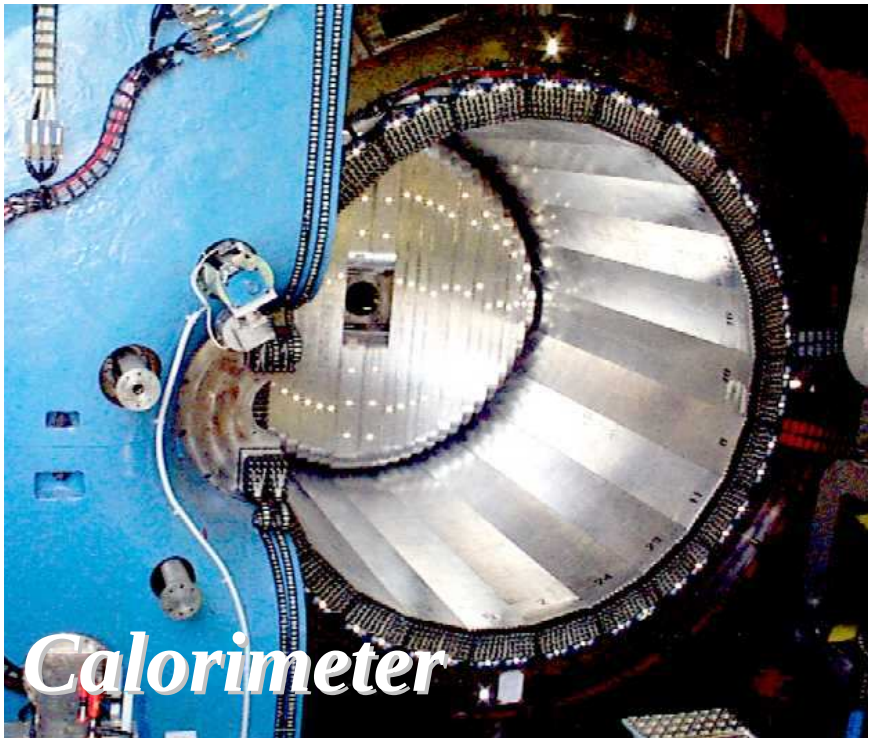


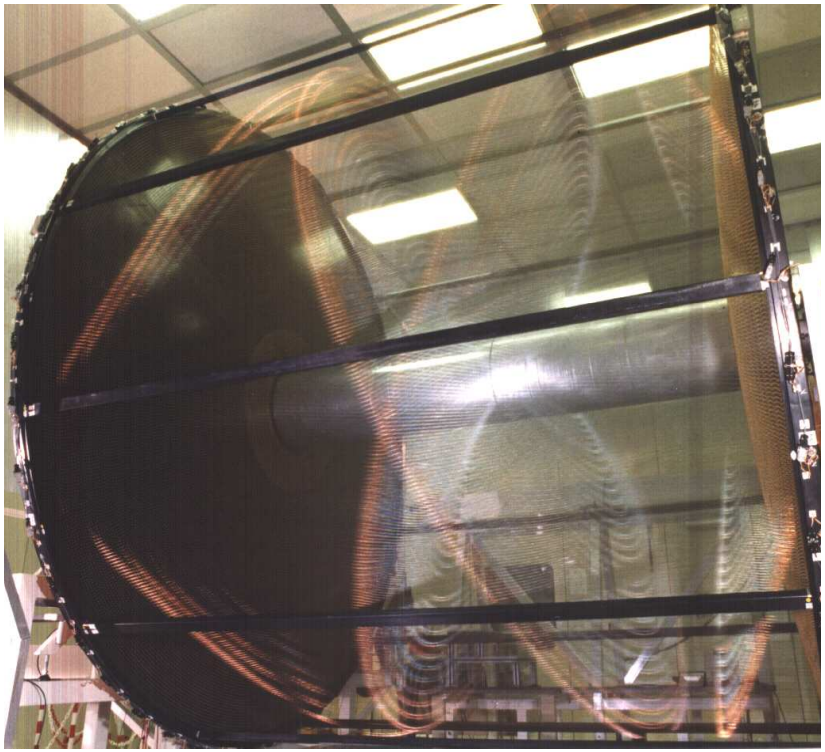
2004 best $\mathcal{L}_{peak}$ 1.2×10^{32} cm^{-2}s^{-1}

2004 avg $\mathcal{L}$ ~6×10^{31}cm^{-2}s^{-1}

Collected 770 pb^{-1} since May 2004

The KLOE detector





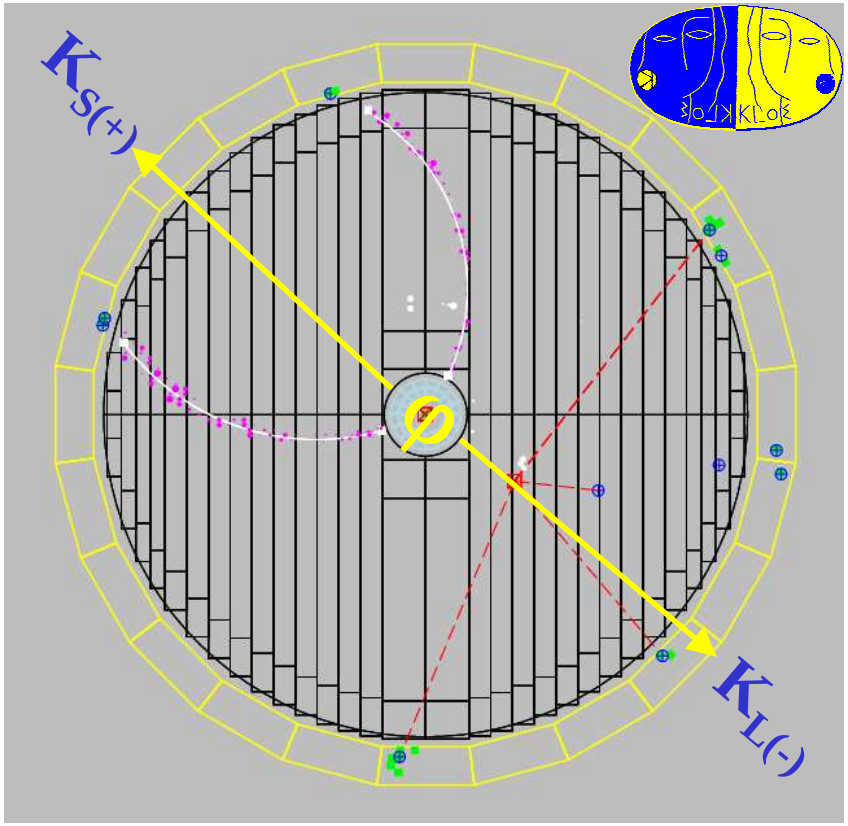
$\sigma(E)/E = 5.7\%/\sqrt{E(GeV)}$
$\sigma(t) = 54\ ps/\sqrt{E(GeV)} \oplus 100\ ps$

$\sigma_p/p = 0.4\ \%$ (tracks with $\theta > 45°$)
$\sigma_x^{hit} = 150\ \mu m$ (xy), 2 mm (z)
$\sigma_x^{vertex} \sim 1$ mm
$\sigma(M_{\pi\pi}) \sim 1$ MeV

Kaons at KLOE

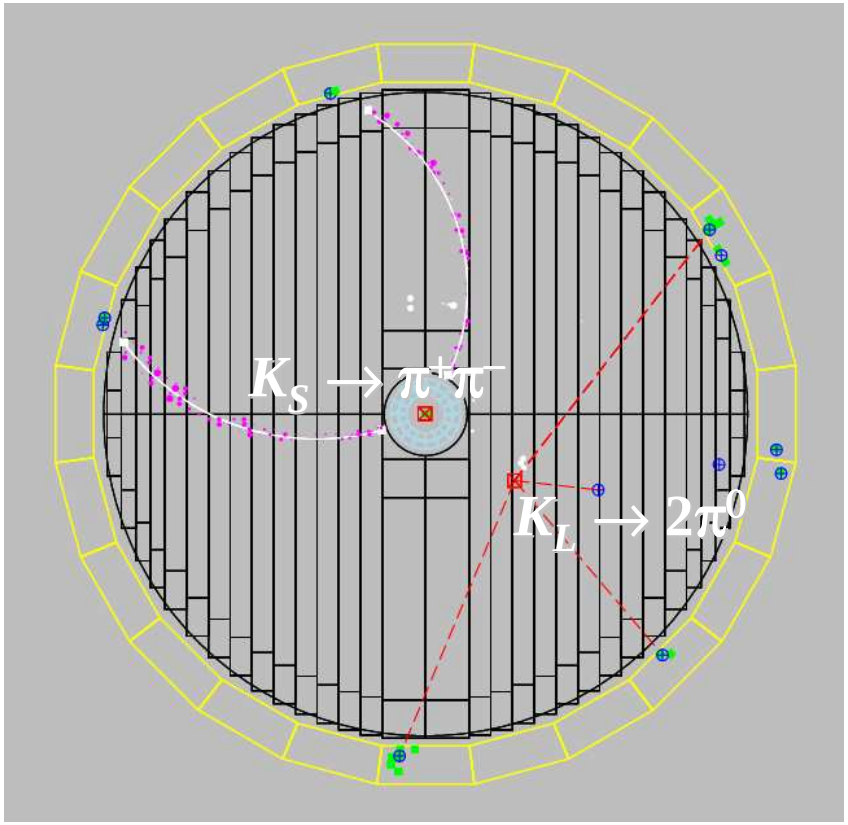
- The φ decays at rest allow us to select monochromatic (p ~ 110 MeV/c) pure beams of Kaons
- Observation of $K_{L,S}$ signals presence of $K_{S,L}$
- K_S decays near IP: λ_S ~ 0.6 cm
- ~50% of K_L decays inside the detector: λ_L ~ 340 cm
- $\lambda_\pm$ ~ 95 cm
- Events per pb^{-1}:

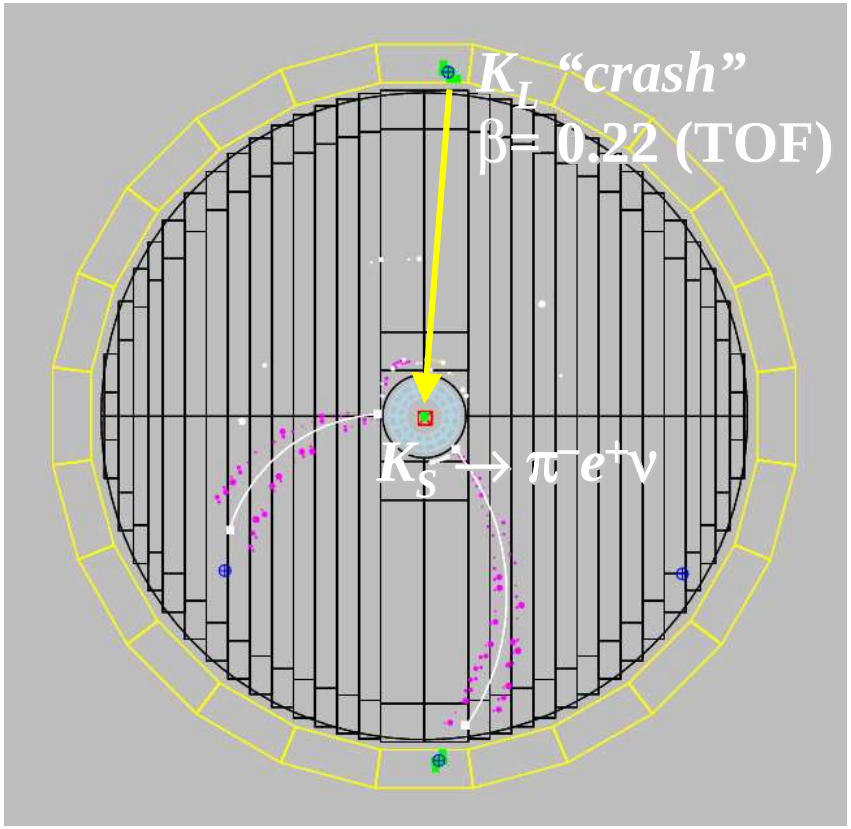
K^+K^-	$1.5\times 10^6/pb^{-1}$
K_LK_S	$10^6/pb^{-1}$



~4 m

Tagging of neutral kaons





K_L tagged by $K_S \rightarrow \pi^+\pi^-$
Efficiency ~ 70%
K_L momentum resolution ~ 1 MeV

K_S tagged by K_L interaction in EmC
Efficiency ~ 30%
K_S momentum resolution ~ 1 MeV

Measurement of K_L BR's

$$BR(K_L \to i) = \frac{N_i}{N_{tag}} \times \frac{1}{\varepsilon(i)_{rec} \times \varepsilon_{FV}(\tau_L) \times \varepsilon_{tag}(i)/\varepsilon_{tag}(all)}$$

Reconstruction efficiencies:

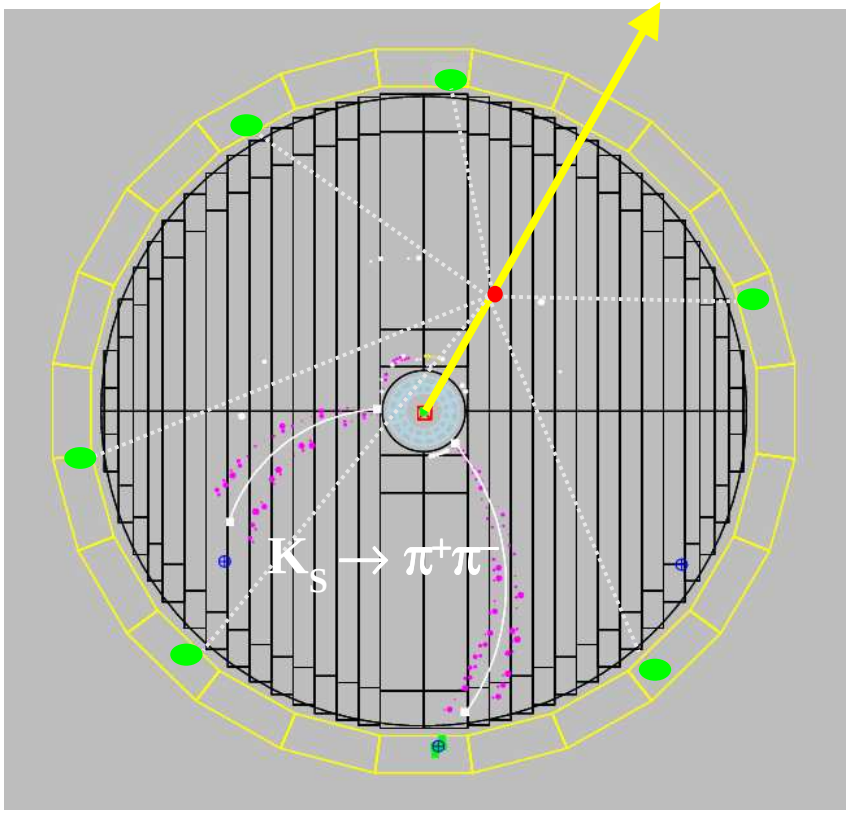
$K_L \to \pi\mu\nu, \pi e\nu$	ε (rec) $\cong$ 55%
$K_L \to \pi^+\pi^-\pi^0$	ε (rec) $\cong$ 40%
$K_L \to 3\pi^0$	ε (rec) $\cong$ 100%

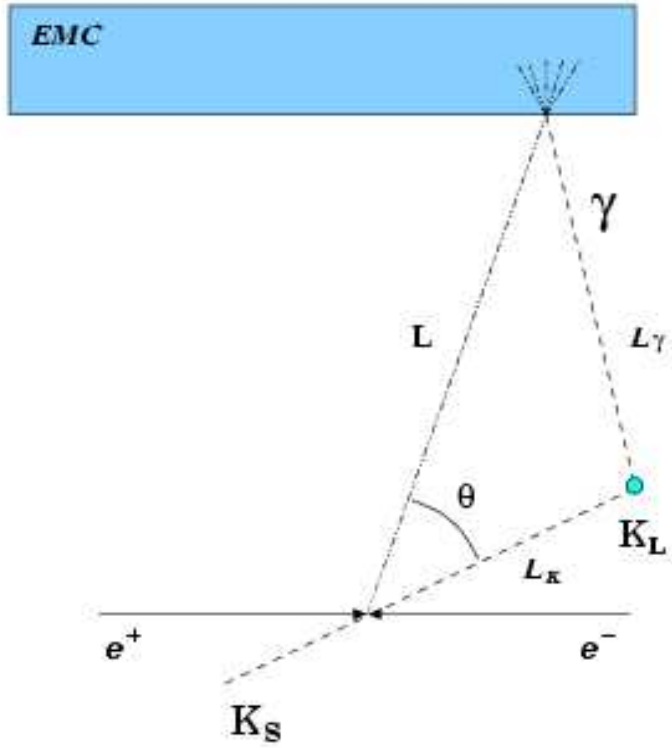
Tagging efficiency

Integral over the fiducial volume:
ε (FV, τ_L) $\cong$ 26%, depends on τ_L

Trigger required on the K_S side

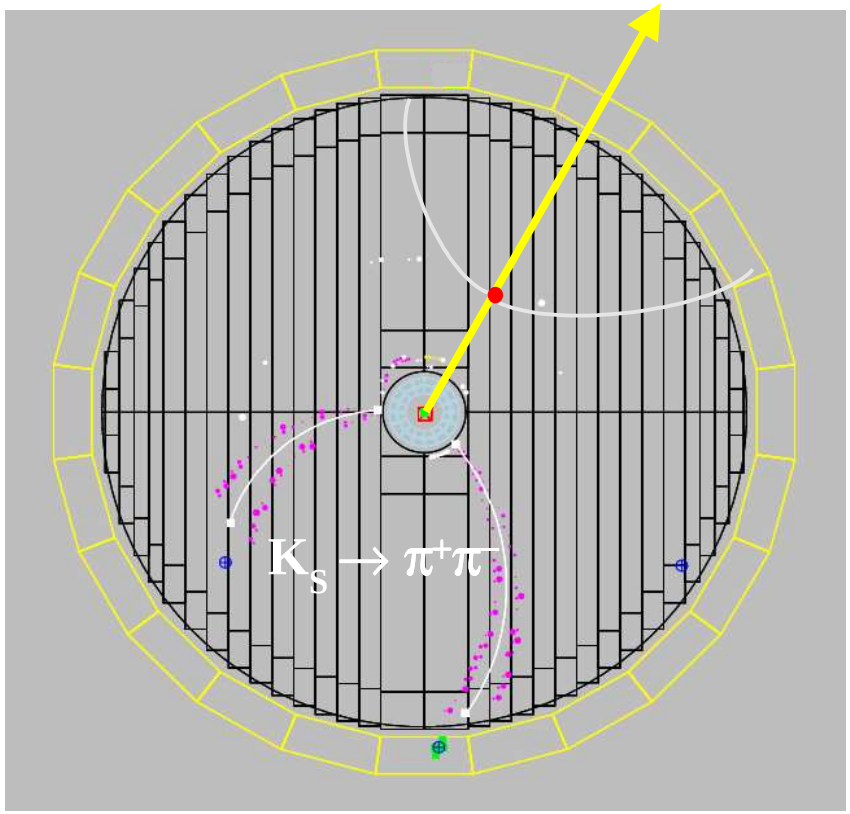
$K_L \rightarrow 3\pi^0$

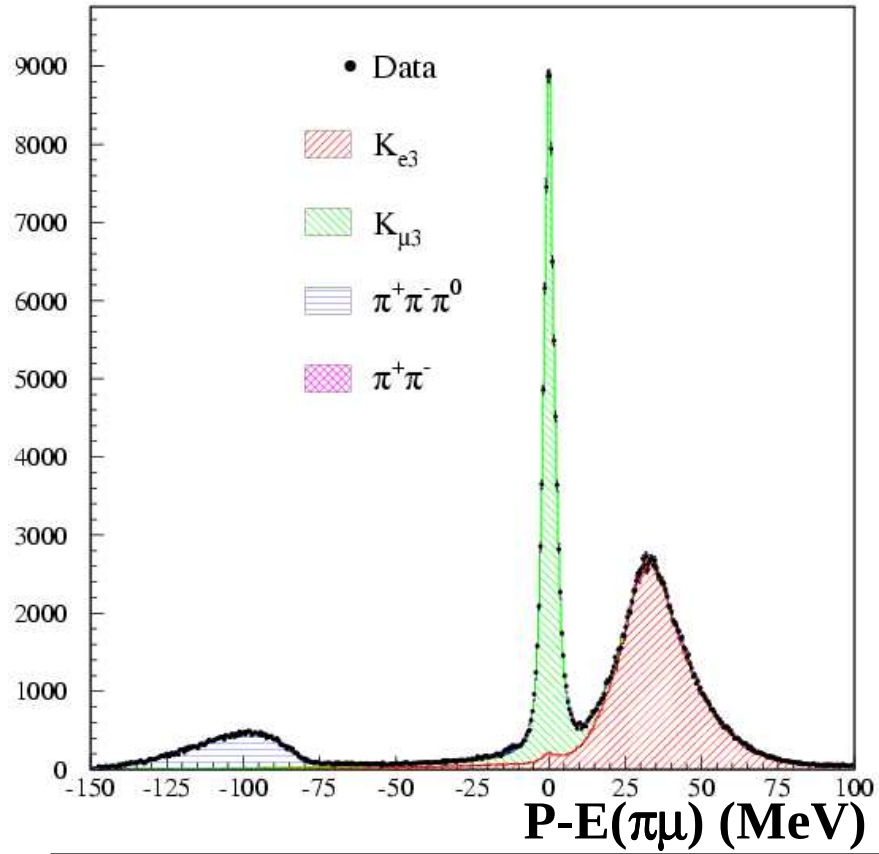




At least 3 neutral cluster
Neutral vertex reconstructed along K_L direction using TOF
Efficiency close to 100%, bkg 1%

$K_L \rightarrow$charged

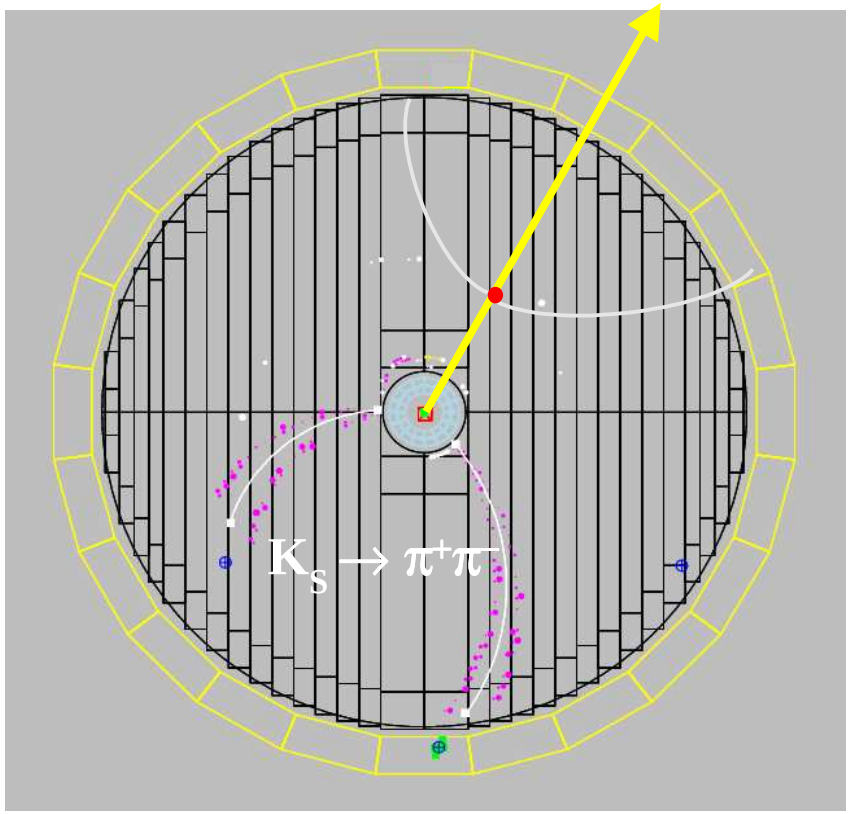


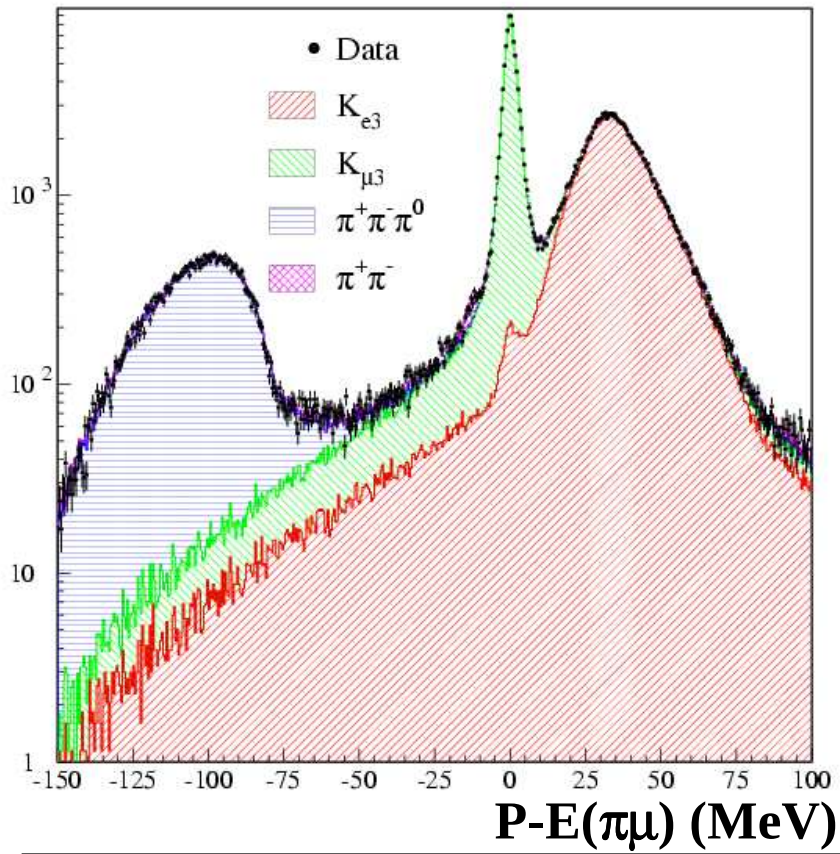


2 tracks forming a vertex along the K_L direction.
Vertex and tracking efficiency ~55% for Kl3 and 40% for 3π

Events counted by fitting missing momentum minus missing energy in the pion-muon hypothesis

$K_L \rightarrow$charged





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Vertex and tracking efficiency ~55% for KL3 and 40% for 3π

Events counted by fitting missing momentum minus missing energy in the pion-muon hyphthesys

Absolute BR's results

- **Absolute BR's results with (τ_{KL} = 51.54 ± 0.44 ns):**

¾ of 2001-2002 data has been used for efficiency evaluation and ¼ for BR measurement corresponding to 13×10^6 tagged K_L.

$BR(K_L \rightarrow \pi e \nu(\gamma)) = 0.4049 \pm 0.0010 \pm 0.0031$ ~8×10^5 events

$BR(K_L \rightarrow \pi \mu \nu(\gamma)) = 0.2726 \pm 0.0008 \pm 0.0022$ ~ 5×10^5 events

$BR(K_L \rightarrow 3\pi^0) = 0.2018 \pm 0.0004 \pm 0.0026$ ~ 7×10^5 events

$BR(K_L \rightarrow \pi^+\pi^-\pi^0(\gamma)) = 0.1276 \pm 0.0006 \pm 0.0016$ ~ 2×10^5 events

Absolute BR's results

We measure ~99.64% of the K_L decays:

$\Sigma_i BR(K_L \rightarrow i)[\tau(K_L)] + 0.0036 \equiv 1 \quad \rightarrow \quad \tau(K_L)$

$\Sigma\, BR(K_L \rightarrow X) = 1.0104 \pm 0.0076$ **Rare decays from PDG**

Assuming $\Sigma\, BR(K_L \rightarrow X) = 1$: $\tau_{KL} = 50.72 \pm 0.14 \pm 0.36$ **ns**

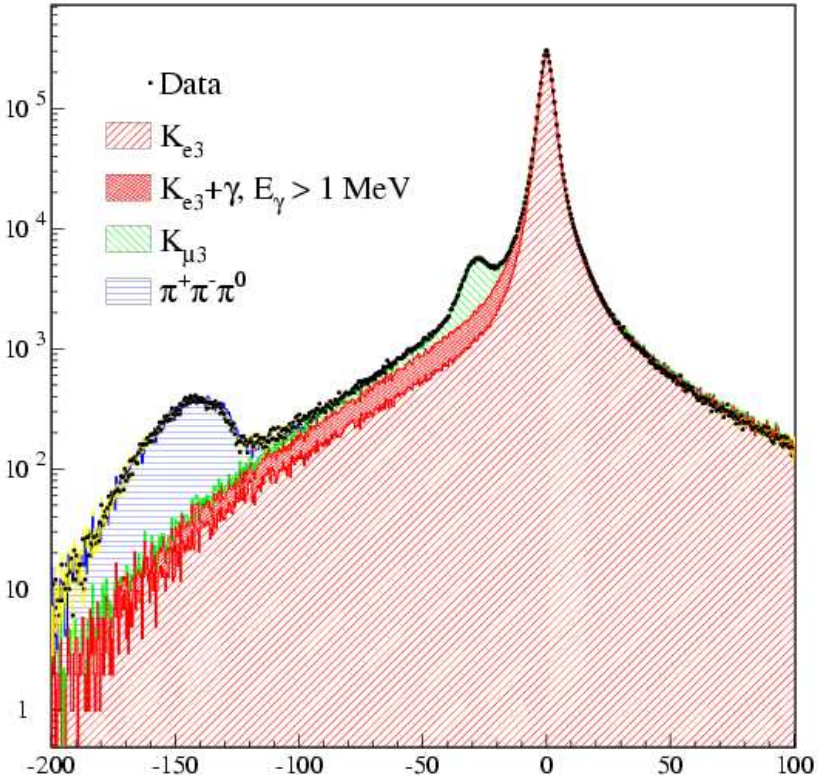
$BR(K_L \rightarrow \pi e \nu(\gamma)) = 0.4007 \pm 0.0006 \pm 0.0014$(tag-trk)

$BR(K_L \rightarrow \pi \mu \nu(\gamma)) = 0.2698 \pm 0.0006 \pm 0.0014$(tag-trk)

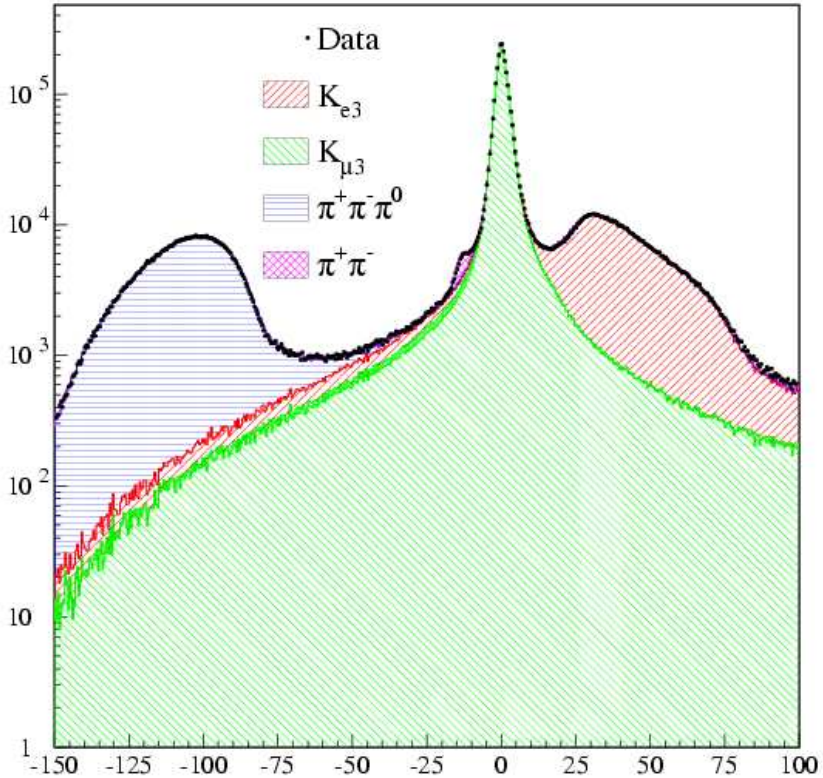
$BR(K_L \rightarrow 3\pi^0) = 0.1997 \pm 0.0005 \pm 0.0019$(event counting)

$BR(K_L \rightarrow \pi^+\pi^-\pi^0(\gamma)) = 0.1263 \pm 0.0005 \pm 0.0011$(tag-trk)

Radiative corrections



P-E(πe) (MeV)



P-E(πμ) (MeV)

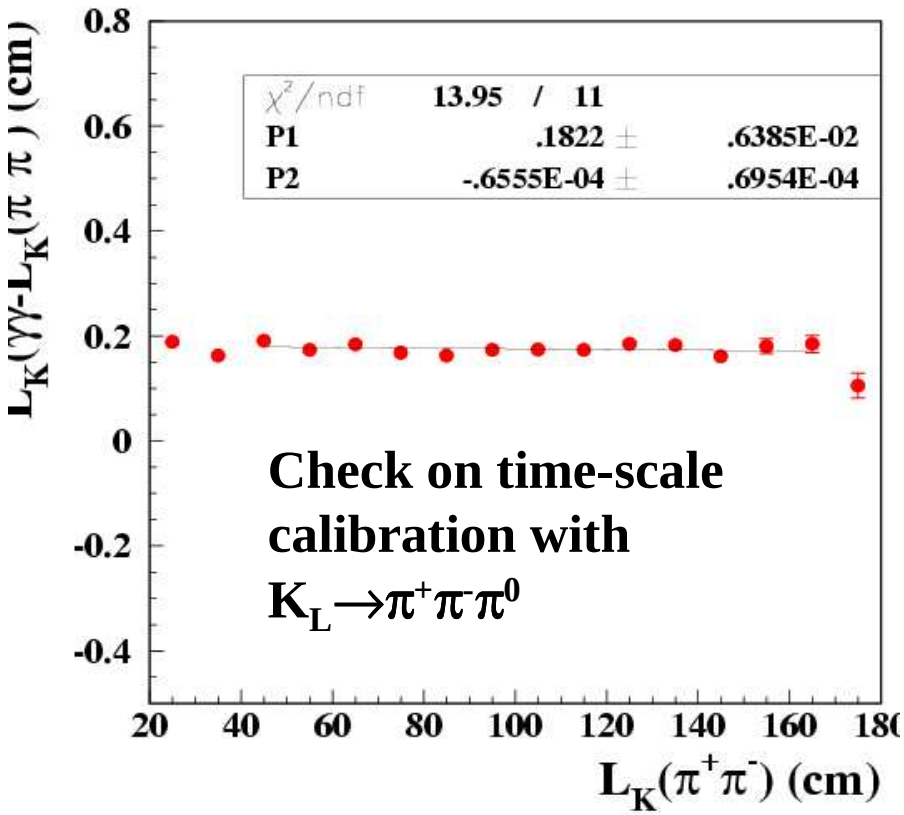
The radiation is included in the MC simulation for all K decays.

The E-P shape is checked using Ke3/Kμ3 enriched samples obtained from an independent calorimetric selection: Tof, E/p, and cluster centroid position.

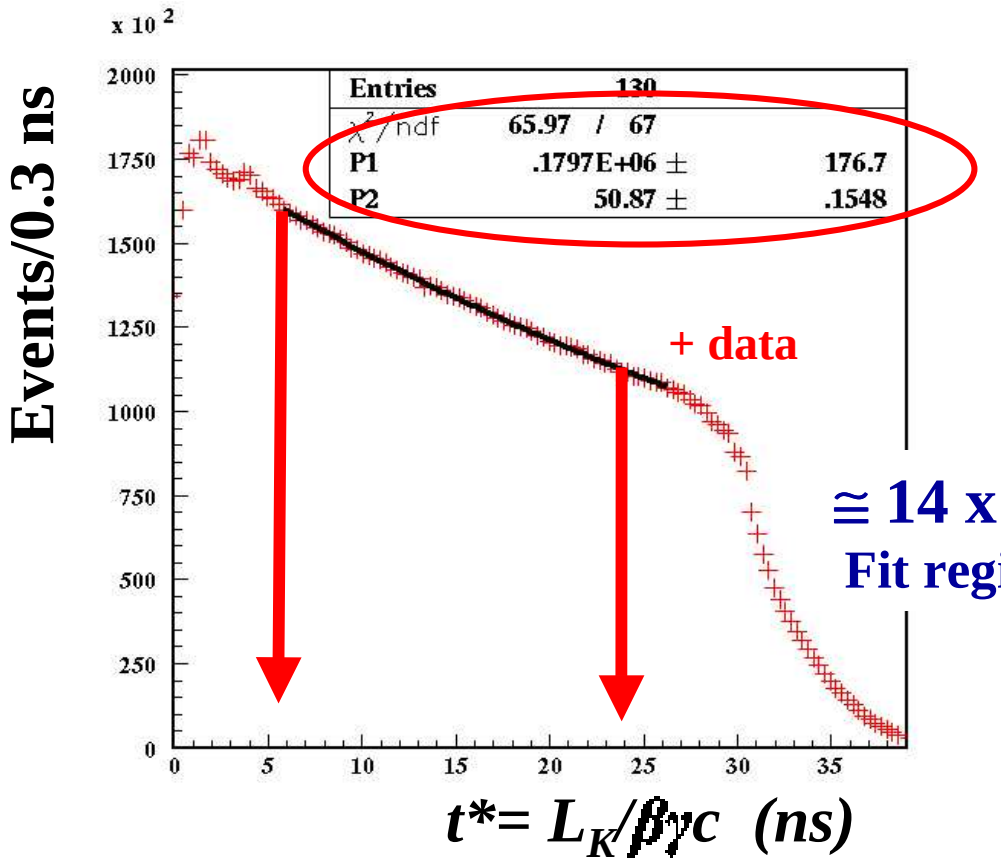
The Ke3 BR changes by 2% neglecting the radiative tail.

K_L lifetime from $K_L \rightarrow 3\pi^0$

- **We measure a large fraction of K_L decay length $\Delta L/\lambda \sim 0.4 \Rightarrow$ high statistical sensitivity to λ**
- **K_L momentum measured from $K_S \rightarrow \pi^+\pi^-$**
- **$K_L \rightarrow 3\pi^0$ efficiency >99% $\Rightarrow$ low sensitivity to efficiency variations along the K_L path**
- **Time scale calibration at 0.1% level $\Rightarrow$ enters directly in the lifetime measurement**
- **$K_L \rightarrow \pi^+\pi^-\pi^0$ as a control sample for the estimate of efficiency and resolution.**



K_L lifetime from $K_L \rightarrow 3\pi^0$



≅ 14 x 10^6 events

Fit region = 6 -26 ns (40% τ_L)

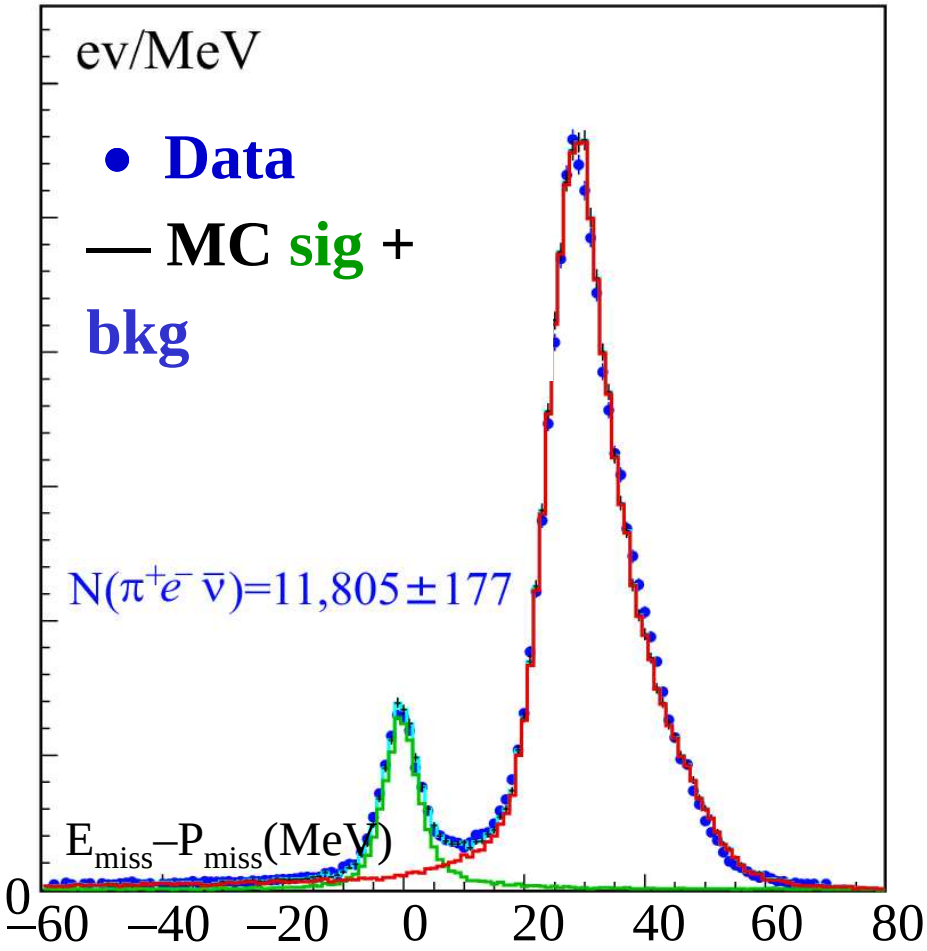
τ (PDG) (fit) = (51.7 ± 0.4) ns

τ (Vosburg, 1972) = (51.54 ± 0.44) ns - 0.4 Mevents

τ_L (KLOE) = (50.87 ± 0.16 ± 0.26) ns - 14.5 Mevents – 440 pb^{-1}

K_S semileptonic decay

- **Selected using Tof technique**
- **Event counting obtained by fitting the E(πe)-P distribution**
- **The two charge modes are measured independently**
- **selected ~10^4 signal events per charge in the 2001-2002 data sample.**



$$BR(K_S \rightarrow \pi e \nu) = (7.09 \pm 0.07_{stat} \pm 0.08_{syst})\ 10^{-4}$$

V_{us} from Kl3 decays and τ_L

Prescription from hep-ph/0411097 (F. Mescia @ICHEP04):

1) Quadratic parametrization of the form factor momentum dependence:

$$f(t) = f(0)\left[1 + \lambda \frac{t}{m_{\pi^+}^2} + \frac{\lambda'}{2}\frac{t^2}{m_{\pi^+}^2}\right]$$

$\lambda_+ = 0.0226 \pm 0.0114$

$\lambda'_+ = 0.0023 \pm 0.0004$

$\lambda_0 = 0.0154 \pm 0.0008$

from KTeV + ISTRA

2) K_L lifetime from KLOE (average of the two measurements) :

$\tau_{KL} = (50.81 \pm 0.23)$ **ns**

3) BRs from KLOE set the sum =1:

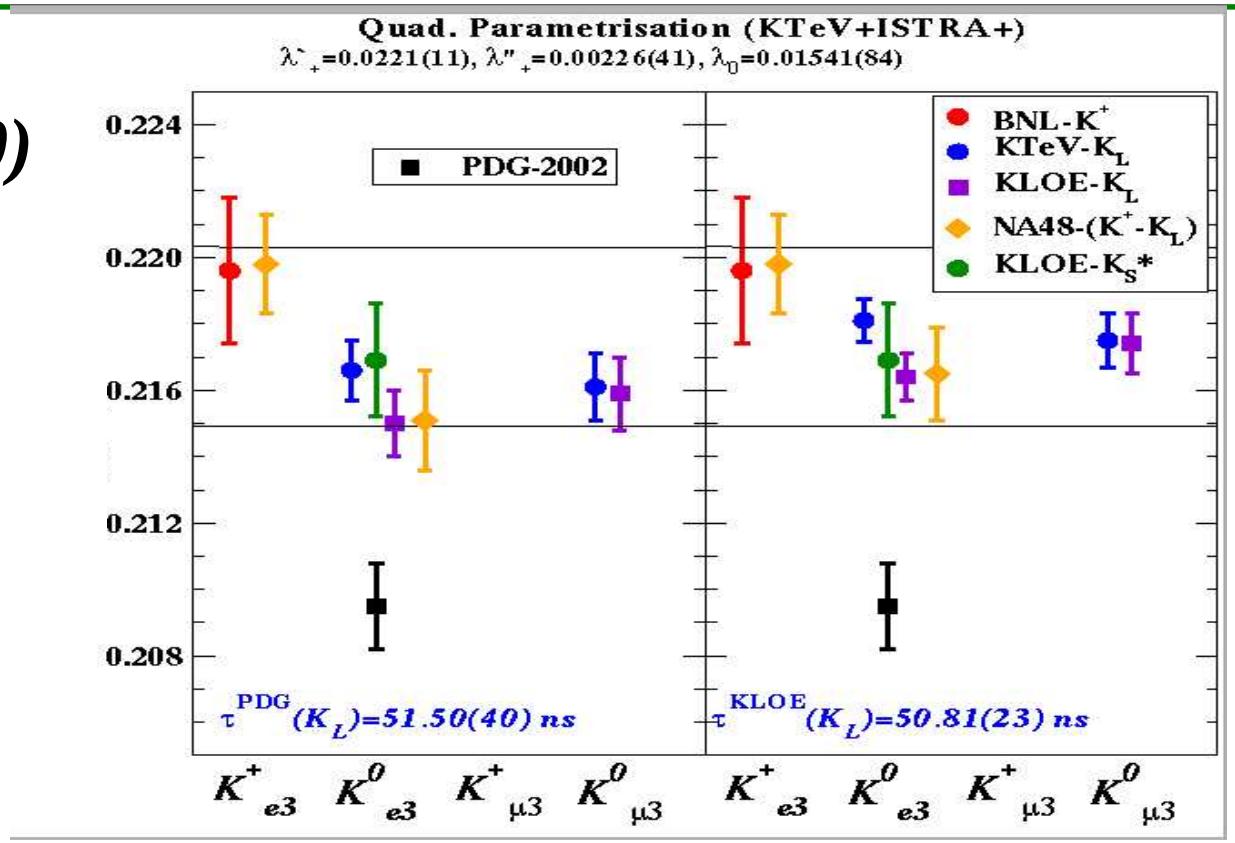
$BR(K_L \to \pi e \nu) = 0.4007 \pm 0.0006 \pm 0.0014$

$BR(K_L \to \pi \mu \nu) = 0.2698 \pm 0.0006 \pm 0.0014$

4) Form factor $f_+^{K\pi}(0)$ **from Leutwyller-Roos:** **0.961(8)**

V_{us} from Kl3 decays and τ_L

$|V_{us}| \times f_+^{K\pi}(0)$



KLOE results: $|V_{us}| \times f_+^{K\pi}(0)\ (K_{Se3}) = 0.2169 \pm 0.0017$

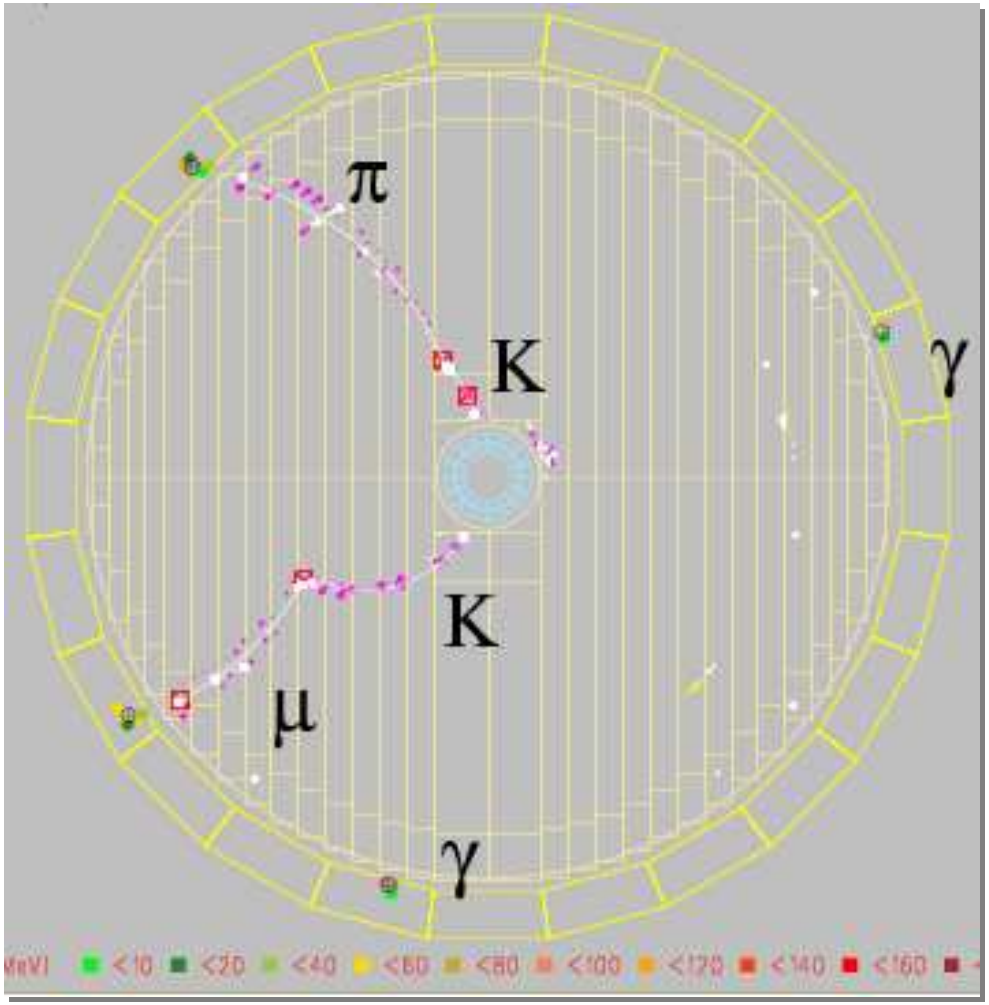
$|V_{us}| \times f_+^{K\pi}(0)\ (K_{Le3}) = 0.2164 \pm 0.0007$

$|V_{us}| \times f_+^{K\pi}(0)(K_{L\mu3}) = 0.2174 \pm 0.0009$

From Unitarity: $(1-|V_{ud}|^2)^{1/2} f_+^{K\pi}(0) = 0.2177 \pm 0.0028$

Tagging of charged kaons

- **Tag performed selecting $K^{\pm} \rightarrow \mu^{\pm}\nu$, $\pi^{\pm}\pi^{0}$ decays (85% of $K^{\pm}$) by measuring the charged particle momentum in the K rest frame (P^{*}).**
- **In the following analyses the trigger is required on the tag side.**



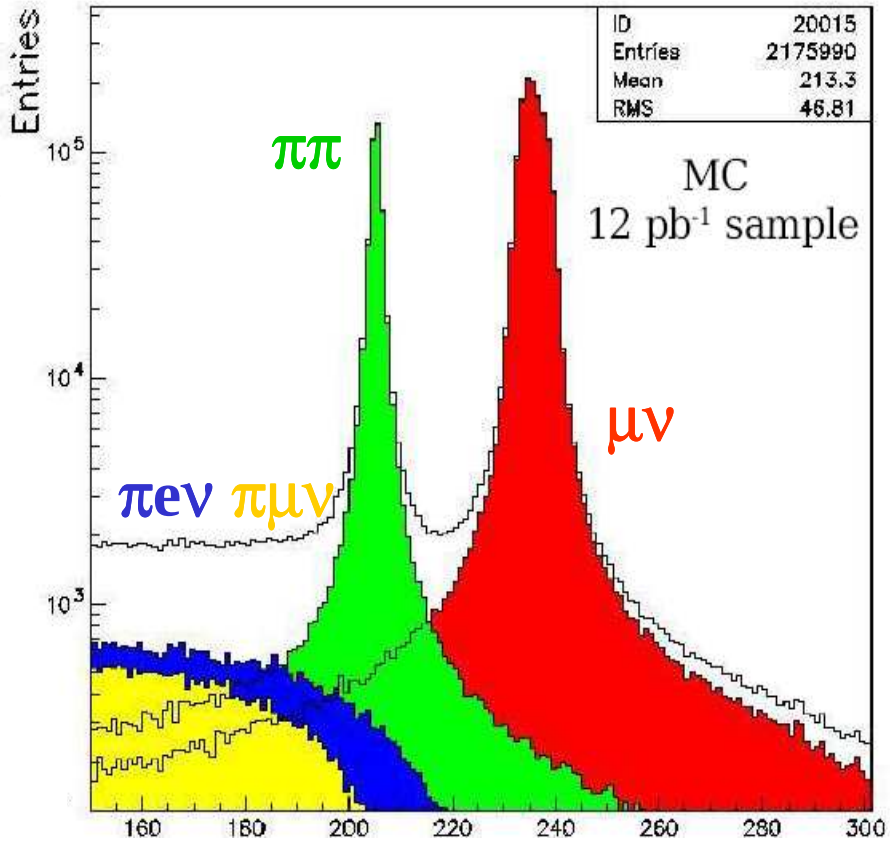
Measurement of BR($K^+ \to \mu\nu(\gamma)$)

Combining the experimental value of
$\Gamma(K \to \mu\nu(\gamma))/\Gamma(\pi \to \mu\nu(\gamma))$
with the ratio
f_K/f_π obtained from lattice calculations
we can extract the ratio $|V_{us}|/|V_{ud}|$
(Marciano hep-ph/0406324)

Selection

- **Negative self-triggering $\mu\nu$-Tag**
- **2002 data ~175 pb^{-1} (2/3 is used as efficiency sample)**
- **Background events identifyied by the presence of a neutral pion.**

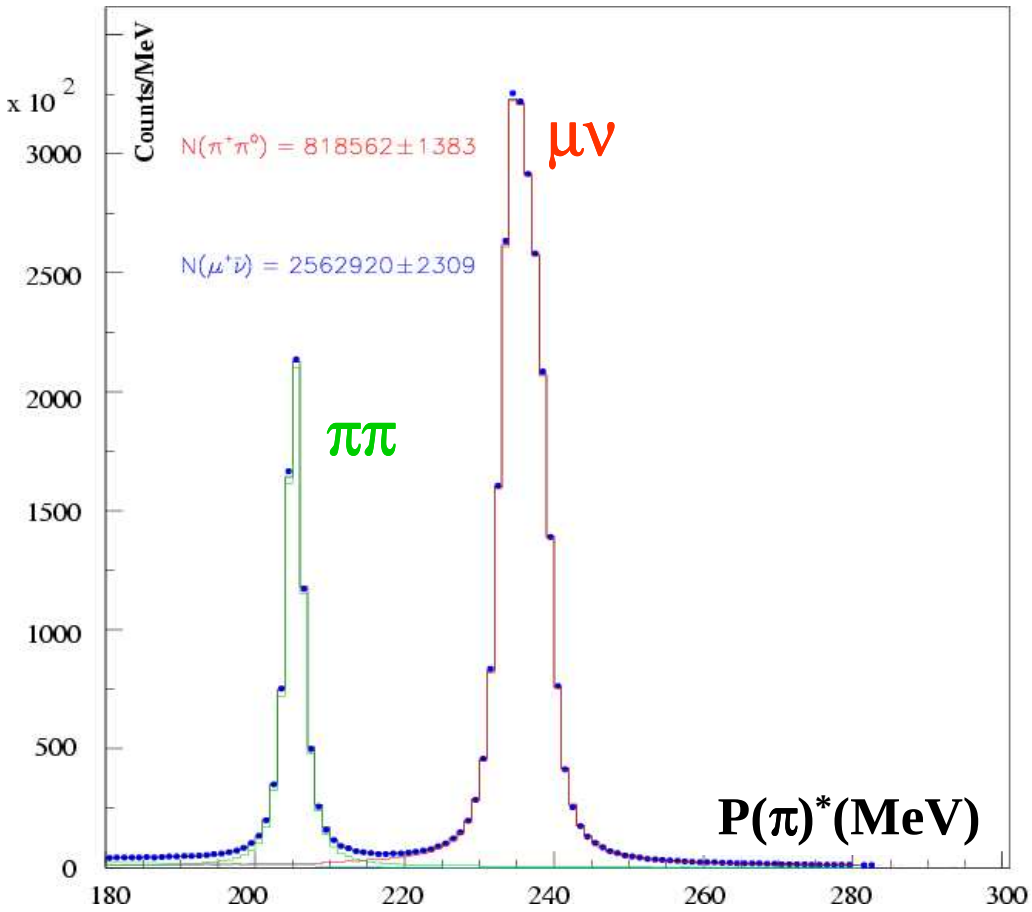
Particle momentum in K rest frame



$P(\pi)^*$(MeV)

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

- **Event counting performed by fitting the P^* distribution with signal and background shapes obtained from data control samples: bkg-sample selected by looking for 2 photons from neutral pion; control sample for signal shape selected by identifying the muon cluster in the Emc. The shapes are properly corrected using MC simulation.**
- **Systematics are dominated by efficiency estimate.**



BR($K^+ \to \mu^+\nu(\gamma)$) = 0.6366 ± 0.0009 (stat.) ± 0.0012 (syst.)

Chiang = 0.6324 ± 0.0044 **PDG fit = 0.6343 ± 0.0017**

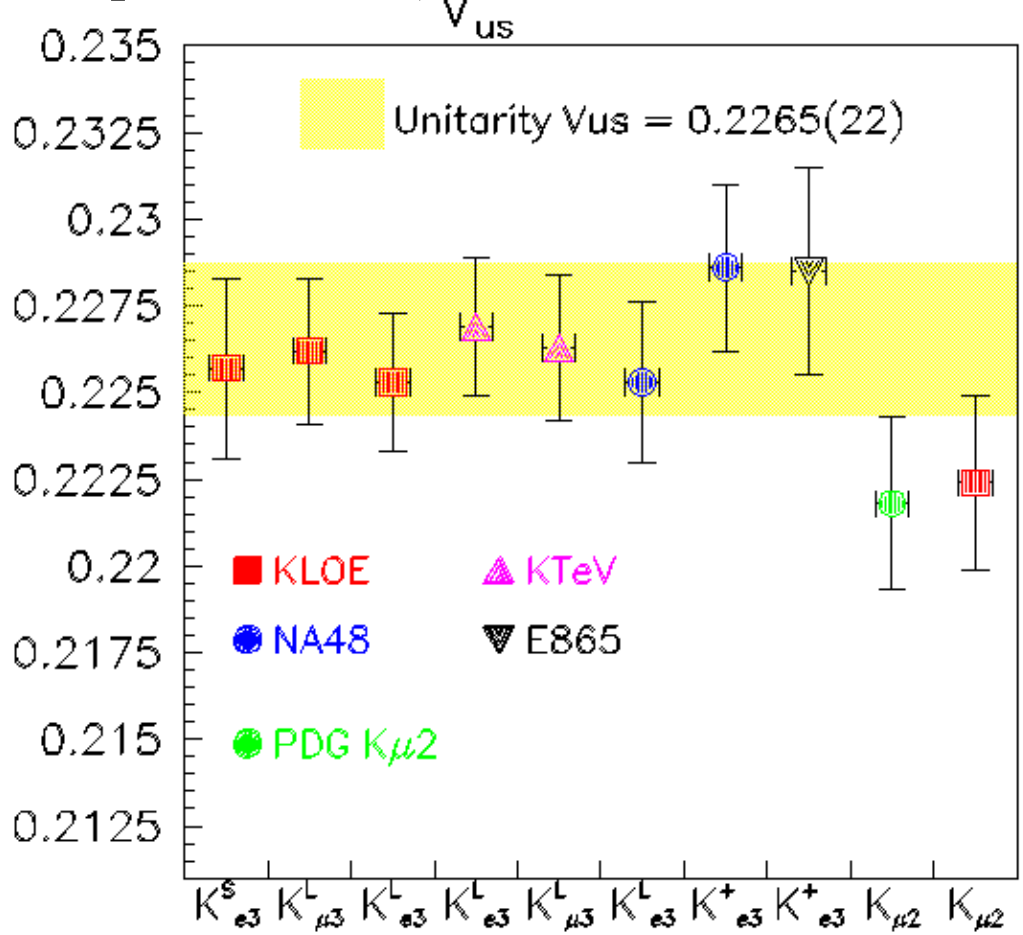
V_{us} from $K^+ \to \mu\nu(\gamma)$

Following the method from Marciano hep-ph/0406324 :

f_K / f_π=1.210±0.014 (MILC Coll. hep-lat/0407028)

Vud=0.9740±0.0005
(superallowed β-decays)

Vus=0.2223±0.0025



Semileptonic decays of $K^{\pm}$

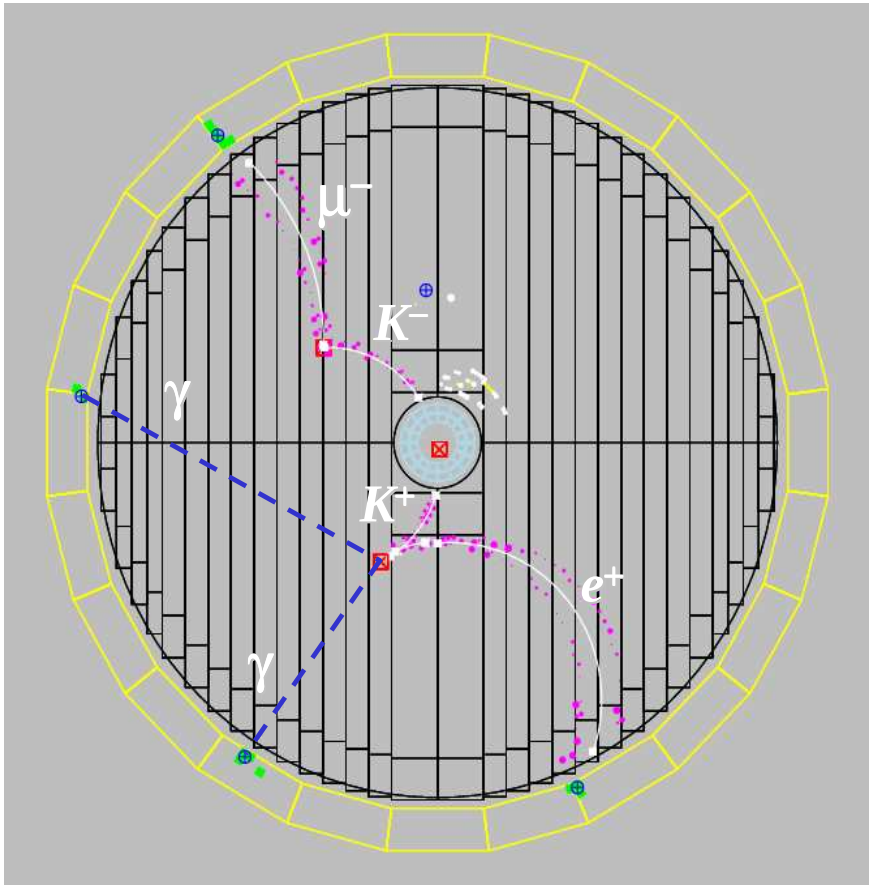
Absolute BR measurement.

$K^{\pm}\rightarrow\mu\nu,\pi\pi$ decays used to tag the events.

K_{l3} selection:

- **kaon decay vertex in FV**
- **Reject two-body decays: $P^{*}(\pi) \leq 195$ MeV**
- **Cut on missing momentum to reject $\pi\pi\rightarrow\pi\mu\nu$ decays.**
- **π^0 search: 2 neutral clusters in EmC, prompt wrt the K vertex.**
- **Spectrum of charged daughter mass, m^2, from TOF measurement.**

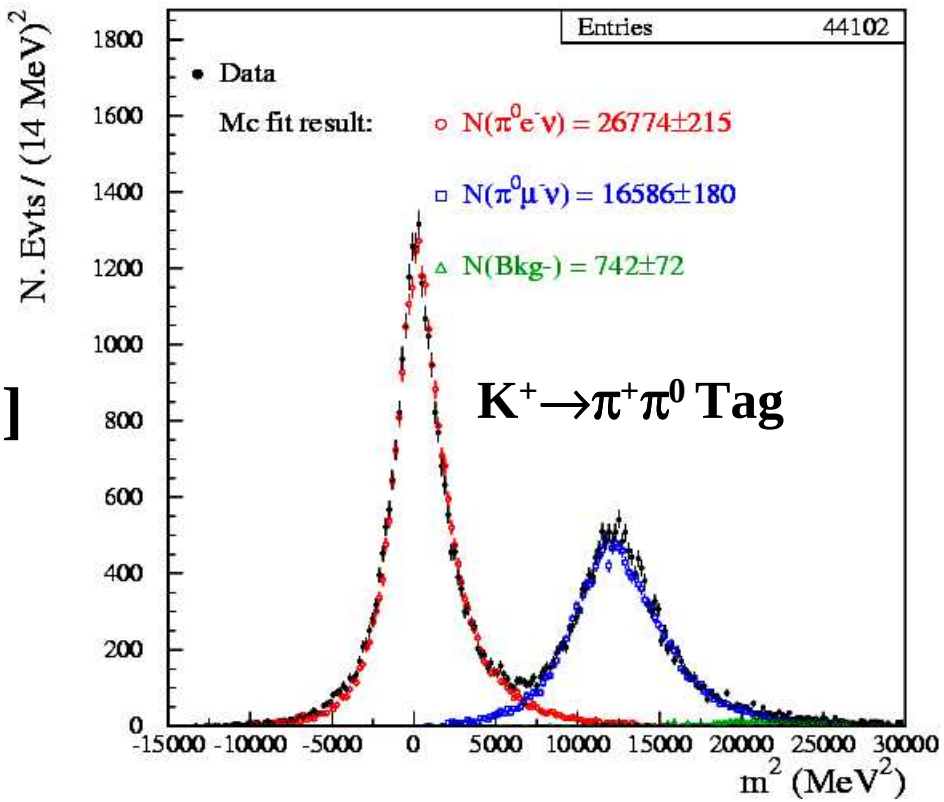
$$m^2=p^2\times[(cT/L)^2-1]$$



- **Ratio of data and MC efficiency is used to correct MC acceptance.**

Semileptonic decays of $K^{\pm}$

$$m_l^2 = p_{TRK}^2 \times [(c(t_l - t_\gamma)/L_{TRK})^2 - 1]$$



	Tag $K^+\mu 2$	Tag $K^+\pi 2$	Tag $K^-\mu 2$	Tag $K^-\pi 2$
N_{Ke3}	67 022 ± 331	26 774 ± 215	71 188 ± 345	25 942 ± 211
$N_{K\mu 3}$	42 096 ± 282	16 586 ± 179	44 925 ± 293	16 465 ± 180

Conclusion

With the data collected in the year 2001-2002 KLOE has measured:

- **The dominant K_L BR's with 0.5% accuracy**
- **The K_L lifetime with 0.6% accuracy**
- **BR($K_S \to \pi e \nu$) with 1% accuracy**
- **BR($K^+ \to \mu^+ \nu$) with 0.2% accuracy**
- **All BR's are inclusive of the radiation**

Final papers are under review by the Collaboration

A large number of $K^\pm$ semileptonic decays has been collected and identified allowing us to measure all the BR's with better than 1% accuracy

KLOE is now measuring:

- **$K^\pm$ lifetime**
- **Kl3 form factor**
- **$K_S \to \pi \mu \nu$ BR**

Coming soon the update of $\Gamma(K_S \to \pi^+\pi^-(\gamma))/\Gamma(K_S \to \pi^0\pi^0)$ measurement

We expect to collect $2fb^{-1}$ for the end of December 2005