KLOE Results and Prospects for K_S Physics

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The KLOE Detector

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

$\sigma_t = 54\ \mathrm{ps} / \sqrt{E(\mathrm{GeV})} \oplus 50\ \mathrm{ps}$

(bunch fluctuations subtracted)

$\sigma_p/p = 0.4\ \%$

(for 90° tracks)

Lead/Scintillating-Fiber calorimeter

He-iC$_4$H$_{10}$ drift chamber

KLOE data taking

- 2×10^{31} cm^{-2}s^{-1} exceeded
- 1 pb^{-1} per day reached
- 35 pb^{-1} collected
- Average trigger rate 2.1 kHz

Year 2000 (23 pb^{-1})

Stream	Events (M)	Volume (GB)
$K^+ K^-$	19	687
$K_S K_L$	64	2270
$\rho\,\pi$	6	166
radiative	23	520
Bhabha	127	2623

10.9 M K_L tagged by $K_S \to \pi^+\pi^-$
7.2 M K_S tagged by K_L interactions in EmC

Useful control samples for calibration

K_S Physics at KLOE

Integrated Lum. (pb^{-1})

2000

1000

100

20

CPT limits ($K_S \to \pi^+ e^- \nu / \pi^- e^+ \nu$ vs $K_L \to \pi^+ e^- \nu / \pi^- e^+ \nu$)

rare and not so rare K_S decays ($\gamma\gamma$, πee, $\pi\mu\mu$, $\pi\nu\nu$)

$BR(K_S \to \pi^+ \pi^-) / BR(K_S \to \pi^0 \pi^0)$

BR of semileptonic K_S decays ($K_S \to \pi e \nu$)

Upper limit on $BR(K_S \to \pi^0 \pi^0 \pi^0) \leq 10^{-5}$

dN/dE_γ ($K_S \to \pi^+ \pi^- \gamma$)

Measuring ratios of K_S BR's

K_S beam: tagged by **K_L interactions** in the calorimeter

$$\frac{\Gamma\,(K_S \to \text{channel a})}{\Gamma\,(K_S \to \text{channel b})}$$

observed *estimated* *desired* ε_S *selection efficiency*

$$N_S^{a,b} - Bkg_S^{a,b} = N_{KK} \times \varepsilon_S(\text{tag}) \times BR_S \times \langle \varepsilon_S \rangle^{a,b}$$

$N_{KK} = \int L\ dt \cdot \sigma_\phi \cdot BR(\phi \to K^0 \overline{K^0})$

drops out identically

ε_S (tag) *almost cancel out*

With tagged beams at KLOE one can also measure absolute BR's

K_S tagging

Clean K_S tagging by time-of-flight identification of K_L interacting in the EmC (β^* = K_L velocity in the ϕ rest frame)

Selection cuts:

- $E_{clus} \geq 100$ MeV
- $|\cos(\theta_{clus})| \leq 0.7$
- $\beta^* \in [0.195, 0.2475]$

T_0 fixing

- Absolute time-zero of the event is fixed ***a posteriori*** using the fastest cluster in the event
- Global time is synchronized to the bunch crossing frequency
- γ hypothesis is used at the first stage of the reconstruction

Tag efficiency is slightly dependent on the K_S decay due to the different global t_0 estimations, given by:

- prompt γ's in $K_S \rightarrow \pi^0\pi^0$
- pion clusters in $K_S \rightarrow \pi^+\pi^-$
- pion or electron clusters in $K_S \rightarrow \pi e \nu$

$$\varepsilon^{+-} / \varepsilon^{00} = (95.030 \pm 0.005)\ \%$$

Ratio of tag efficiencies is estimated directly from data

$K_S \rightarrow \pi^0\pi^0$ selection

Selection:

- K crash
- $|t - R/c| \leq \min(5\,\sigma_t\,;\,3\text{ ns})$
- $\cos\theta < 0.9$
- $E > 20$ MeV

# prompt	3	4	≥ 5
DATA	37.5 %	61.8 %	0.7 %
MC thr	36.7 %	63.0 %	0.3 %

All numbers normalized to ≥3 cluster

• prompt clusters distribution:
DATA vs. Monte Carlo

$K_S \rightarrow \pi^0\pi^0$ Data vs Monte Carlo

Photon detection efficiency: estimated from data $\phi \rightarrow \pi^+\pi^-\pi^0$

- 4 prompt clusters:
  Energy spectrum and angular distribution
- Total energy distribution

Selection efficiency: $\varepsilon_{00} = (56.7 \pm 0.1)$ %

$K_S \rightarrow \pi^0 \pi^0$ trigger efficiency

1. Assignment of the clusters to the K_S and K_L hemievent cutting at **–15 ns**
2. Cluster → trigger sector → unbiased multiplicities
3. $1-\varepsilon_{trig} = S(0)\bullet L(0) + S(1)\bullet L(0) + S(0)\bullet L(1)$

$\varepsilon_{trig} = 99.69 \pm 0.03\ (stat) \pm 0.02\ (syst)$

$K_S \rightarrow \pi^+\pi^-$ selection

- K crash
- 2 tracks from IP:
  - closest approach: $|z| \leq 10$ cm; $d_{xy} \leq 4$ cm
  - first hit: $|z| \leq 40$ cm; $d_{xy} \leq 40$ cm

- acceptance and momentum cuts:
  - $30 < \theta < 150$
  - $120 \leq p \leq 300$ MeV/c (to reject $\phi \rightarrow K^+K^-$)
  - Both tracks have to impinge to the calorimeter

$K_S \rightarrow \pi^+\pi^-$ selection efficiency

- Conditional reconstruction efficiency is estimated from data subsamples
- Selecting 1 track according to previous cuts, look for the second one with

$$p_{2,\ \mathrm{estimated}} = p_\phi - p_L - p_1$$

- The correlation between the two particles in the efficiency is mostly due to the acceptance
- A flat correction is applied to the Monte Carlo
- Systematic error is estimated comparing the plateau for different run periods

Selection efficiency:
$\varepsilon_{+-} = (58.5 \pm 0.1)\ \%$

t_0 and trigger efficiency corrections

1. Single particle efficiencies are estimated using $K_S \to \pi^+\pi^-$ subsamples and $K_L \to \pi e \nu$, $\phi \to \pi^+ \pi^- \pi^0$ control samples

t_0
trigger
} pion efficiencies from data (in bins of p_T and θ) for $\pi^+, \pi^-, \mu^+, \mu^-$

2. Weighted mean of the Monte Carlo kinematics, for events with 2 selected tracks

$$\varepsilon^{t0+trg} = \varepsilon_L \times \varepsilon_{t0} + (1-\varepsilon_L)\, \varepsilon^1_{t0\cdot trig} = 96.5\%$$

$\varepsilon_L =$ K_L crash trigger efficiency = (40.5 ± 2.5)%

3. Systematic error:
   - Montecarlo statistics
   - Errors on the efficiencies estimated from data

$K_S \to \pi^+\pi^-/K_S \to \pi^0\pi^0$ result

PDG 2000	Ratio = $2.197 \times [1 \pm 1.2 \times 10^{-2}$ (stat) $\pm 0.6 \times 10^{-2}$ (syst)]
KLOE 1999	Ratio = $2.237 \times [1 \pm 0.4 \times 10^{-2}$ (stat) $\pm 0.7 \times 10^{-2}$ (syst)]
KLOE 2000	Ratio = $2.23 \times [1 \pm 0.35 \times 10^{-2}$ (stat) $\pm 1.5 \times 10^{-2}$ (syst)]
	preliminary ***Systematics under study***

Contribution to systematics	%
Tag bias	1
$K_S \to \pi^0\pi^0$ selection	1
$K_S \to \pi^0\pi^0$ trigger	0.02
$K_S \to \pi^+\pi^-$ selection	0.1
$K_S \to \pi^+\pi^-$ trigger and t0	0.5
Total	1.5

About γ from $K_S \rightarrow \pi^+\pi^- (\gamma)$

- Theoretical estimates of BR($K_S \rightarrow \pi^+\pi^- (\gamma)$) / BR($K_S \rightarrow \pi^0\pi^0$) need definition of γ cutoff energy

- PDG: BR($K_S \rightarrow \pi^+\pi^- (\gamma)$) = $(1.78 \pm 0.4) \times 10^{-3}$ for $E_\gamma > 20$ MeV, below our present statistical precision

- Effective γ energy cutoff due to signal selection (loose momentum cut) must be greater than 20 MeV

- $\pi^+\pi^-$ invariant mass distribution + presence of γ in calorimeter will be used to explicitly measure γ energy spectrum

$K_S \rightarrow \pi e \nu$

Events selection summary

- Kcrash tag
- Kinematics preselection
- Track to cluster association
- Time of flight identification
- Close kinematics

Normalization to $K_S \rightarrow \pi^+\pi^-$

- Kcrash tag bias estimation

Kinematics preselection

•Two tracks of opposite charge from a vertex in the fiducial volume:

$\rho < 4$ cm and $|z| < 8$ cm

•Cut:

-invariant mass $M_{\pi\pi}$ ($\pi\pi$ hypothesis)

-K_S momentum P_{KS} in the ϕ rest frame

•Efficiency taken directly from Monte Carlo

$\varepsilon = (62.4 \pm 0.3)$ %

•Efficiency estimation from $K_L \rightarrow \pi e \nu$ decays before the drift chamber wall (work in progress)

Track to cluster association (TCA)

- Extrapolation of both tracks to the calorimeter surface is required. Acceptance from Monte Carlo:

$$\varepsilon_{GEO} = (51.1 \pm 0.2)\ \%$$

- Both tracks associated to calorimeter clusters: cut on impact parameter (d_{PCA})

d_{PCA} (cm)

•Among all clusters with $d_{PCA} < 30$ cm, the one with maximum energy is used for time of flight identification

TCA T0 and Trigger efficiencies

•2 methods to estimate TCA, T_0 and calorimeter trigger efficiencies:

1. Single particle efficiencies taken from data using $K_S \rightarrow \pi^+\pi^-$ subsamples and $K_L \rightarrow \pi e \nu$, $\phi \rightarrow \pi^+\pi^- \pi^0$ control samples. Efficiencies for π^+ , π^- , μ^+ , μ^- , $e^\pm$ used to weight the Monte Carlo:

   $\varepsilon = (82.1 \pm 0.5)$ %

2. Efficiencies directly from data using $K_S \rightarrow \pi^+\pi^-$, $K_L \rightarrow \pi e \nu$ control sample, selected using DC information only.

   $\varepsilon = (81.4 \pm 0.6)$ %

$\varepsilon_{TCA+T0+TRG} = (81.7 \pm 0.5)$ %

Time of flight identification

- Main background from $K_S \rightarrow \pi^+\pi^-$ ($\pi \rightarrow \mu\nu$ before the DC wall)
- Mass hypothesis are used

$$\delta t\ (\text{mass}) = t_{cl} - \text{length} / c\,\beta(\text{mass})$$

- Independence with respect to the global T_0 estimation

$$D\delta t\ (\text{mass1}, \text{mass2}) = \delta t\ (\text{mass1}) - \delta t\ (\text{mass2})$$

- Two cuts applied:

1. $|D\delta t\ (\pi, \pi)| > 1.5$ ns
2. $|D\delta t\ (\pi, e)| < 1$ ns, $|D\delta t\ (e, \pi)| > 3$ ns

$K_S \rightarrow \pi e \nu$ from MC

Data Summer 2000

Time of flight efficiency

$D\delta t$ distributions in $K_L \rightarrow \pi e \nu$ before the DC wall used to evaluate the efficiency

Efficiency for the cut $|D\delta t\ (\pi, \pi)|$ $\varepsilon_1 = (91.5 \pm 0.5)\ \%$

Efficiency for the cut $|D\delta t\ (\pi, e)|$ $\varepsilon_2 = (91.8 \pm 0.5)\ \%$

Total efficiency $\varepsilon_{TOF} = (84.0 \pm 0.6)\ \%$

Kinematic identification

Kinematics closed with K_S momentum estimated using:

- direction of the K_L cluster
- ϕ 4-momentum

$E(\text{missing})_{\pi e} = E_S - E_\pi - E_e$

Signal yield estimation:

•Data fit using MC spectra for background and signal

•Log-likelihood function takes into account contribution due to finite MC statistics

$K_S \to \pi e \nu$ results

Data: 2000 ~ 11.5 pb^{-1}

overall efficiency $\varepsilon_{TOT} = (21.8 \pm 0.3)\%$

Yield $N(K_S \to \pi e \nu) = 283 \pm 19$ events

In a 5 MeV window
$$\begin{cases} N(K_S \to \pi e \nu) = 248 \pm 17 \text{ events} \\ N(K_S \to \pi\pi) = 9.0 \pm 1.4 \text{ events} \end{cases}$$

PDG 2000* $BR(K_S \to \pi e \nu) = [7.2 \pm 1.2] \times 10^{-4}$ (75 ± 13 events)

$\Gamma_S = \Gamma_L$ $BR(K_S \to \pi e \nu) = [6.70 \pm 0.07] \times 10^{-4}$

KLOE 2000 $BR(K_S \to \pi e \nu) = [7.47 \pm 0.51(\text{stat})] \times 10^{-4}$

preliminary ***Systematics under study***

*CMD-2 @ VEPP-2M Phys. Lett. **B456**(1999)90-94

Conclusions and perspectives

- The measurement of $K_S \rightarrow \pi^+\pi^-$ / $K_S \rightarrow \pi^0\pi^0$ branching ratio has been presented.
- A first measurement of $K_S \rightarrow \pi e \nu$ branching ratio has been obtained using a subsample of 2000 data. The statistical error is a factor of 2 lower than that of the only existing measurement.
- Better understanding on systematics is needed:
  - Tag efficiency bias
  - Photon counting
- Work is in progress on:
  - $K_S \rightarrow \pi^+\pi^-\gamma$
  - $K_S \rightarrow \pi^0\pi^0\pi^0$
  - $K_S \rightarrow \gamma\gamma$