Status of the NA48 experiment at CERN measuring direct CP violation

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on ElectroWeak Interactions and Unified Theories

❖ on behalf of the **NA48 COLLABORATION**:
Cagliari-Cambridge-CERN-Dubna-Edinburgh-Ferrara-Firenze-Mainz-Orsay-Perugia-Pisa-Saclay-Siegen-Torino-Vienna-Warsaw

Outline

- The NA48 experiment
  - Method
  - Beams
  - Detector

- 97 performance and status of 97 data analysis (preliminary)
  - Performance of main detector components and triggers
  - K_S Tagging
  - Lifetime weighting and fiducial volume definition
  - $K_{L,S} \to \pi^+\pi^-$ event selection, background
  - $K_{L,S} \to \pi^0\pi^0$ event selection, background
  - Energy scale and other sources of systematics
  - $K_L \to e^+e^-\gamma$

- 1998 Data Taking
  - Improvements and achievements
  - $K_L \to \pi^+\pi^-e^+e^-$

- Prospects and conclusions

Introduction

Previous precision measurements
of the direct CP violation parameter $\mathrm{Re}(\varepsilon'/\varepsilon)$
in the Kaon system :

NA31	$(23 \pm 6.5) \cdot 10^{-4}$
E731	$(7.4 \pm 5.2 \pm 2.9) \cdot 10^{-4}$

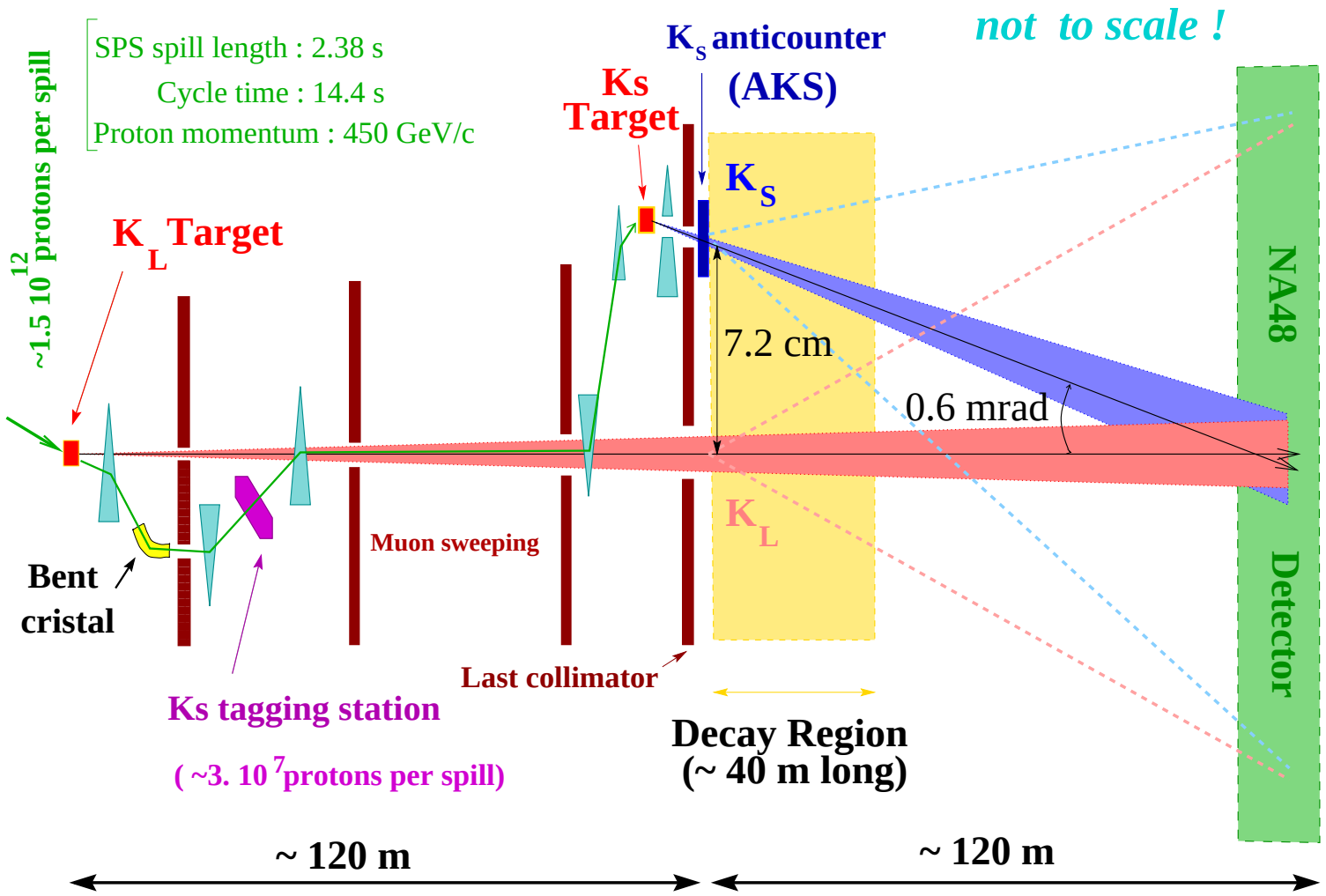
NA48 objective : Determine $\mathrm{Re}(\varepsilon'/\varepsilon)$
to an accuracy of 2×10^{-4}

Double ratio technique :

$$\mathrm{R}= \frac{\Gamma(\mathrm{K_L} \to \pi^0\pi^0)}{\Gamma(\mathrm{K_S} \to \pi^0\pi^0)} \Big/ \frac{\Gamma(\mathrm{K_L} \to \pi^+\pi^-)}{\Gamma(\mathrm{K_S} \to \pi^+\pi^-)} \approx 1 - 6 \times \mathrm{Re}(\varepsilon'/\varepsilon)$$

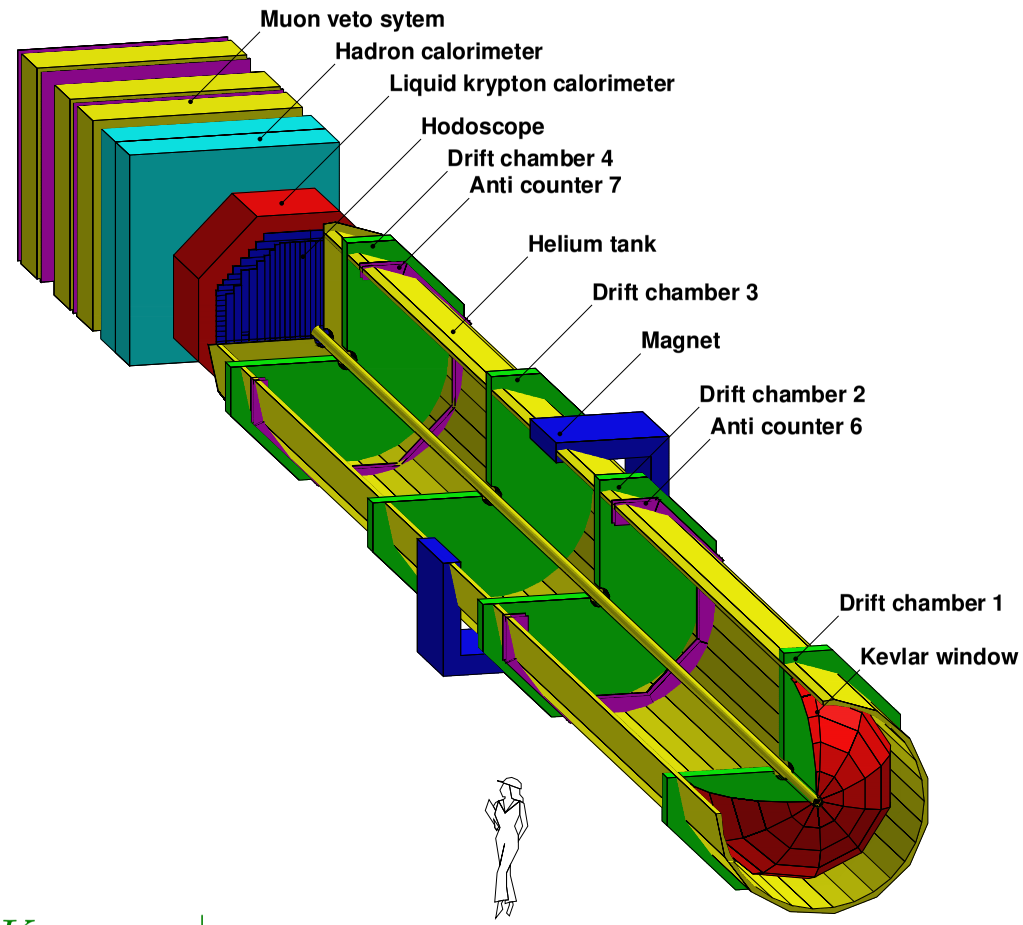
- Collect *several* 10^6 $\mathrm{K_L} \to \pi^0\pi^0$ (limiting mode)
- Minimal corrections achieved by
  - Simultaneous measurement of all 4 modes (K_L/K_S distinguished by K_S tagging)
  - Using the same fiducial volume : K_L longitudinal vertex distributions are made similar to K_S by lifetime weighting
  - Good resolutions and small background levels are achived by using a magnetic spectrometer for the $\pi^+\pi^-$ mode and a Liquid Krypton homogeneous calorimeter for the $\pi^0\pi^0$ mode

Simultaneous K_S and K_L Beams



K_S are distinguished from K_L by tagging the protons upstream of the K_S target

Detector



- $K_{L,S} \rightarrow \pi^+\pi^-$
  - magnetic spectrometer ($P_\perp{}^{kick} \sim 256 MeV/c$)
  - event time measured with a scintillator hodoscope
- $K_{L,S} \rightarrow \pi^0\pi^0$
  - quasi-homogeneous Liquid Krypton e.m. calorimeter :
    - high granularity (13212 $2 \times 2cm^2$ cells)
    - projective geometry
- Background rejection
  - $K_{\mu 3}$ - Muon Veto system
  - K_{e3} - E(LKr)/p(spectrometer)
  - $K_L \rightarrow 3\pi^0$ - based on good time, energy and position resolution of LKr calorimeter

The 1997 Run

Sept/Oct 1997 : first Re(ε'/ε) run

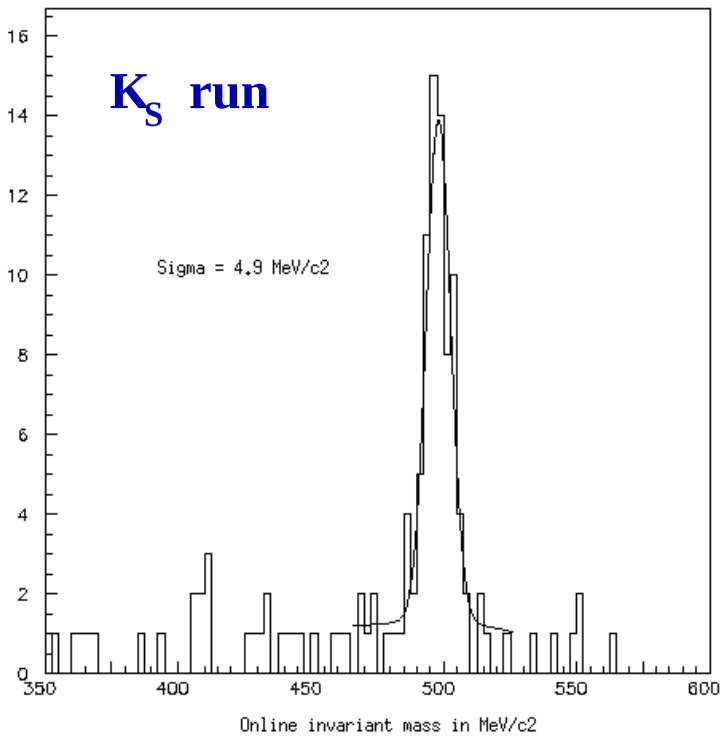
- Installation and commissioning of the entire Read-out of the LKr

- 2/3 of nominal beam intensity
- 42 days of data taking
- 25 Tbytes of data written on tape
  - Read-out 80 Mbytes/s
  - $\sim$ 12 K events recorded per spill

$\Rightarrow \sim 650\ 000\ \mathrm{K_L} \rightarrow \pi^0\pi^0$ with $\begin{cases} 70GeV < E_K < 170GeV \\ 0 < \tau < 4.0\tau_S \end{cases}$

Charged Trigger

- Level 1 : Hodoscope and Total energy in calorimeters
- Level 2 : Fast tracking in the spectrometer
  hardware coordinate builder
  farm of processors : reconstruction of vertex and mass

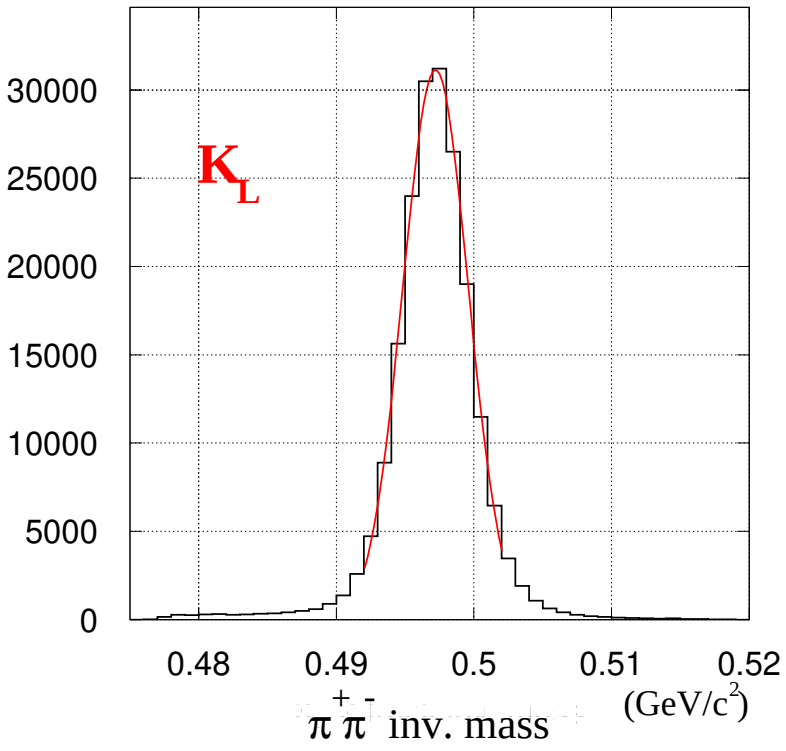


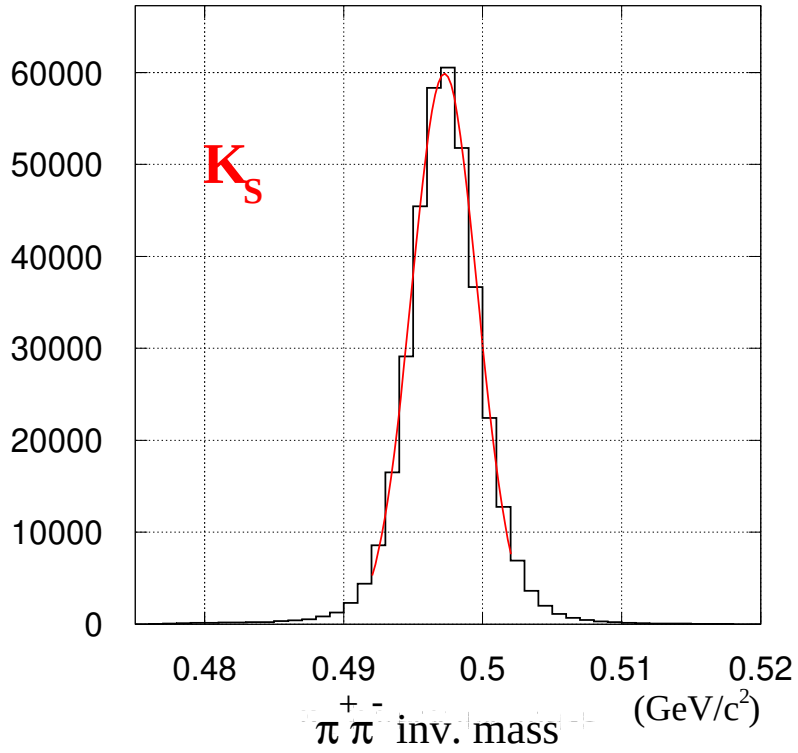
Run '97

- Typical Level 2 rates
  - rate of K_L decays in the detector : $\sim$ 500 kHz
  - output from Level 1 : $\sim$ 70 KHz
  - Rejection factor of Level 2 :$\sim$ 50
  - Dead time $\sim$ 1 % (applied to neutrals)
- Combined $L1 \cdot L2$ efficiency :
  - K_S : $(90.61 \pm 0.08)\%$
  - K_L : $(90.66 \pm 0.10)\%$

$K_{L,S} \to \pi^+\pi^-$: Spectrometer performance

Mass resolution : ~ 2.5 MeV/c^2

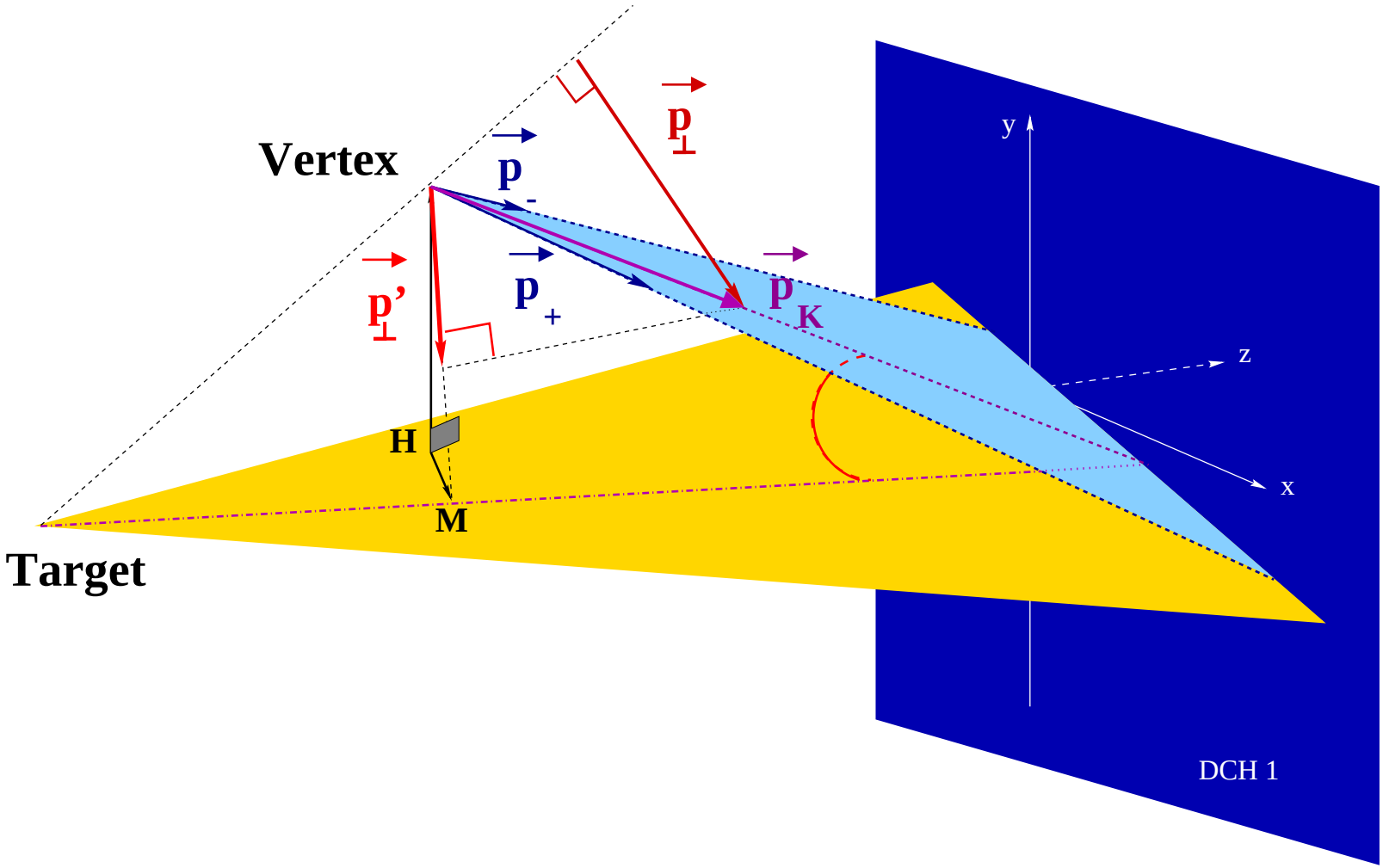




$$\frac{\sigma(\mathrm{P})}{\mathrm{P}} = 0.48\ \% \oplus 0.009\ \mathrm{P[GeV/c^2]}\ \%$$

(from e^- scan at 25 and 100 GeV)

Charged Background : $P_\perp{}^2$

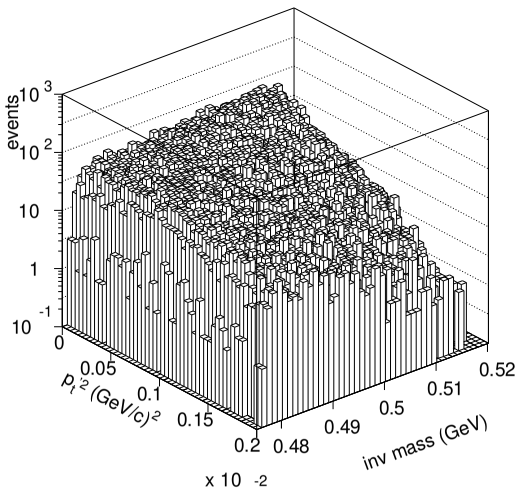


Because of the different target positions, $P_\perp{}^2$ is very different for K_S and K_L .
$P'_\perp{}^2$: more suitable variable

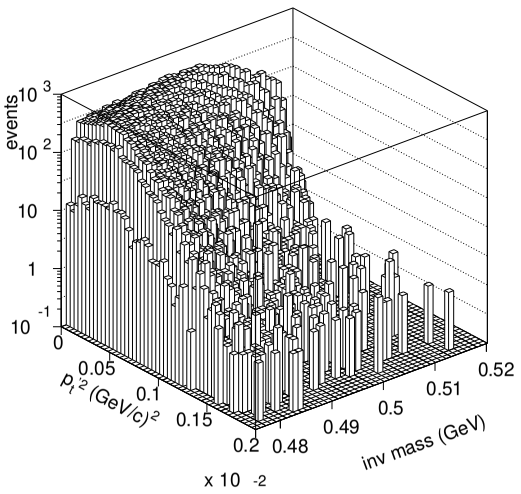
Charged Background : $P'_{\perp}{}^2$ vs Mass

K_{e3} & $K_{\mu 3}$ $\sim 10^2$ times more frequent than $K_L \to \pi^+\pi^-$

Identified K_{e3} (E/P)

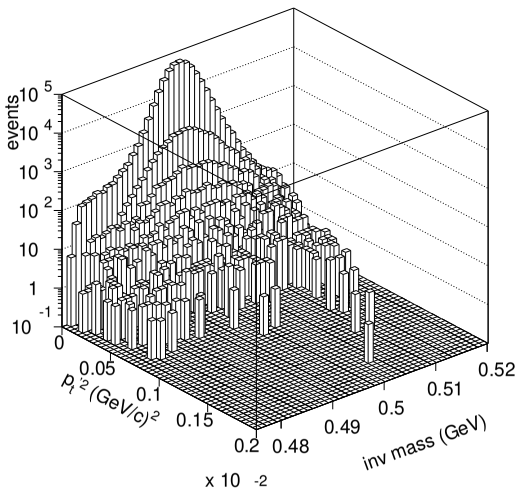


Identified $K_{\mu 3}$ (muon counters)

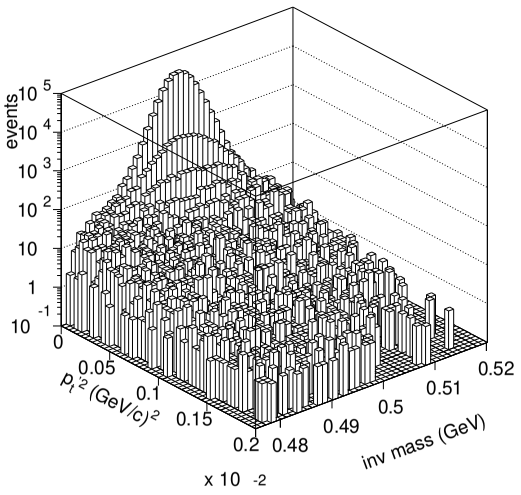


Shape of the background is evaluated in the mass vs $P'_{\perp}{}^2$ plane with selected samples of K_{e3} and $K_{\mu 3}$.

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

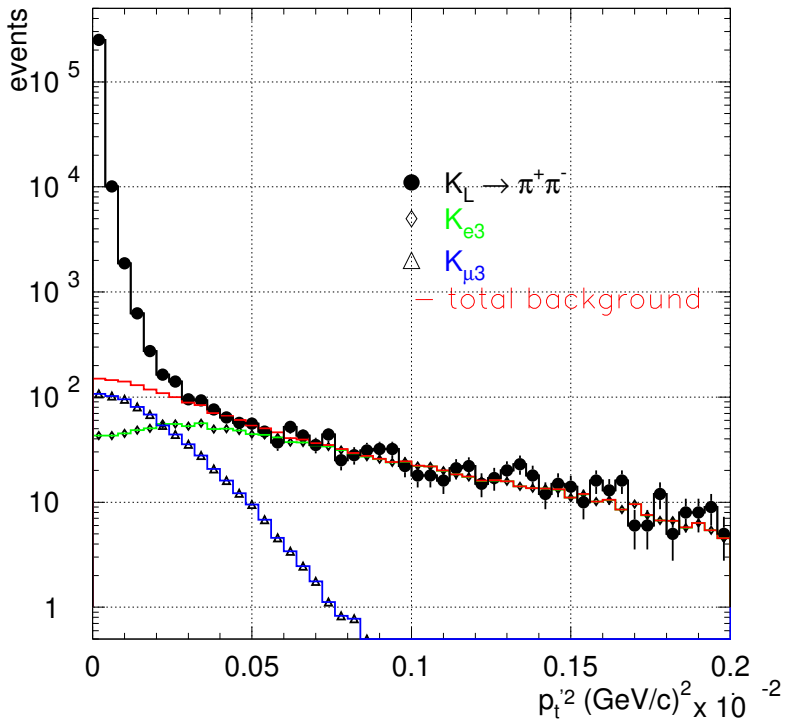


$K_L \to \pi^+\pi^-$ (+ background)



The amount of remaining K_{e3} and $K_{\mu 3}$ is then evaluated in control regions and extrapolated to the signal region.

Charged Background : Estimation



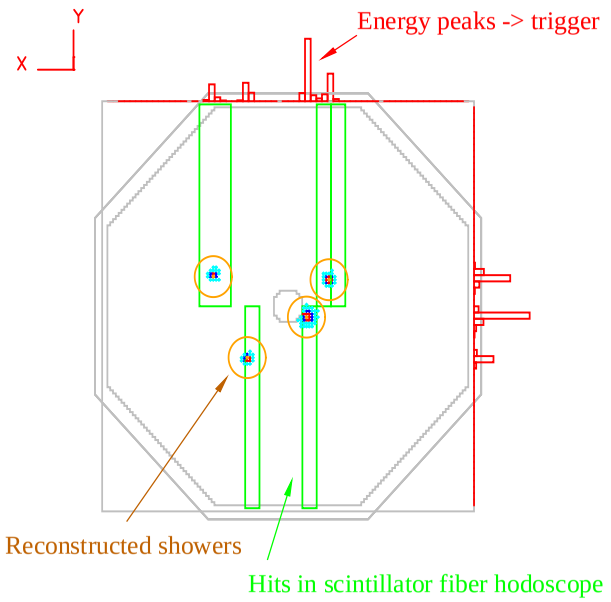
Charged background kept at the $\lesssim 0.3\%$ level

Neutral Trigger

Fully pipelined software trigger based on the calorimeter cells information.

- Reduce the information of the calorimeter to 64 vertical and 64 horizontal projections.

- Compute and cut on :
  - number of in time clusters in each projection
  - Total energy in the calorimeters
  - Decay vertex position



Run '97 :

- Rates

  Input rate $\sim$ 500 kHz K_L decays in detector.

  Output rate $\sim$ 2 kHz

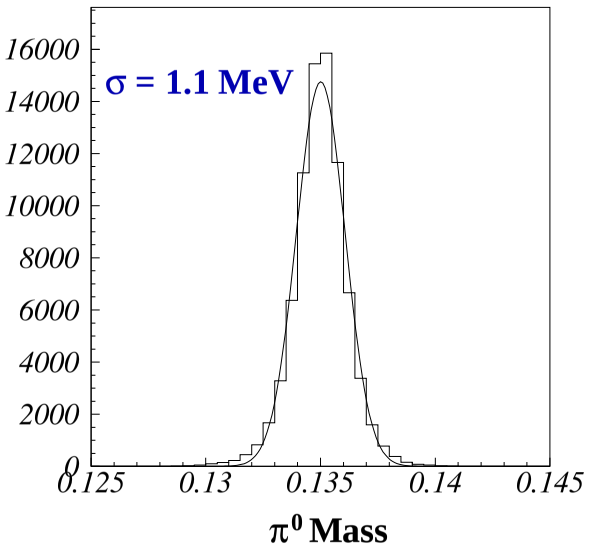
- Efficiency $\approx$ 99.9 %

The e.m. Calorimeter

- Operation :
  - reduced HV (1.5 kV) due to capacitor problem
    $\Rightarrow$ $\sim 20\%$ increase in the electronic noise
    $\Rightarrow$ small space charge effect ($< 0.5\%$)
  - One column (4 cm wide) not connected to HV

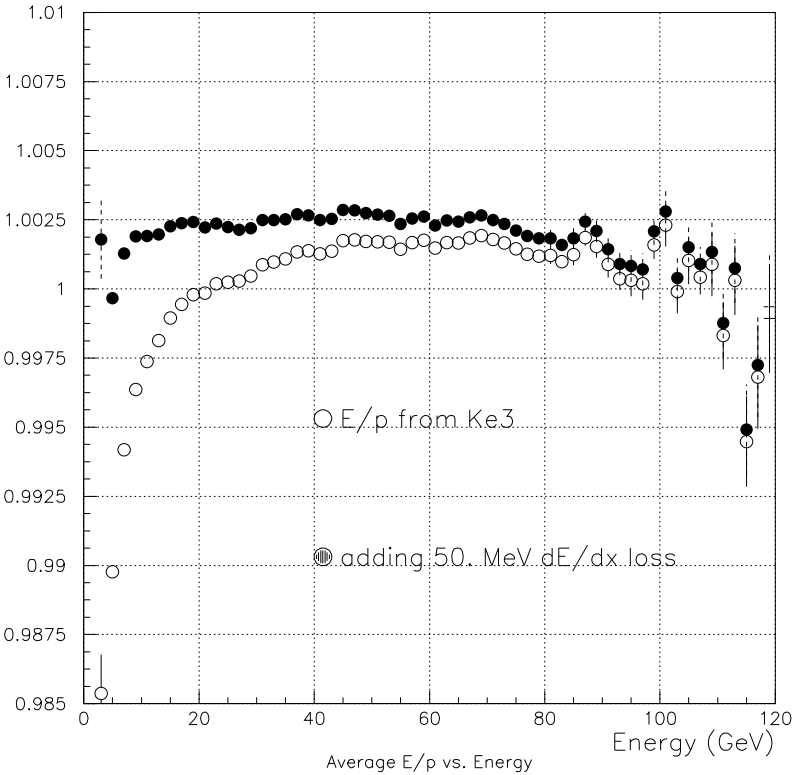
- Calibration :
  - Electronics gain checked regularly
  - Each cell corrected by a factor measured using a K_{e3} sample

- Reconstruction
  $K_{L,S} \rightarrow 2\pi^0 \rightarrow 4\gamma$
  - Vertex position imposing the Kaon mass
  - Pairing the photons to get the best π^0 combination

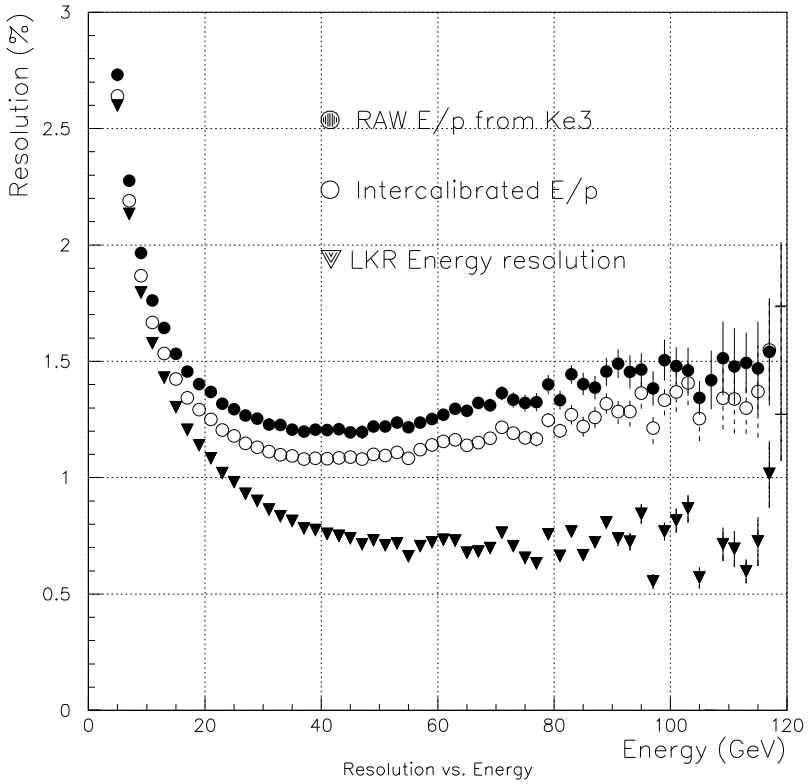


Linearity and Resolution

With electrons from K_{e3}



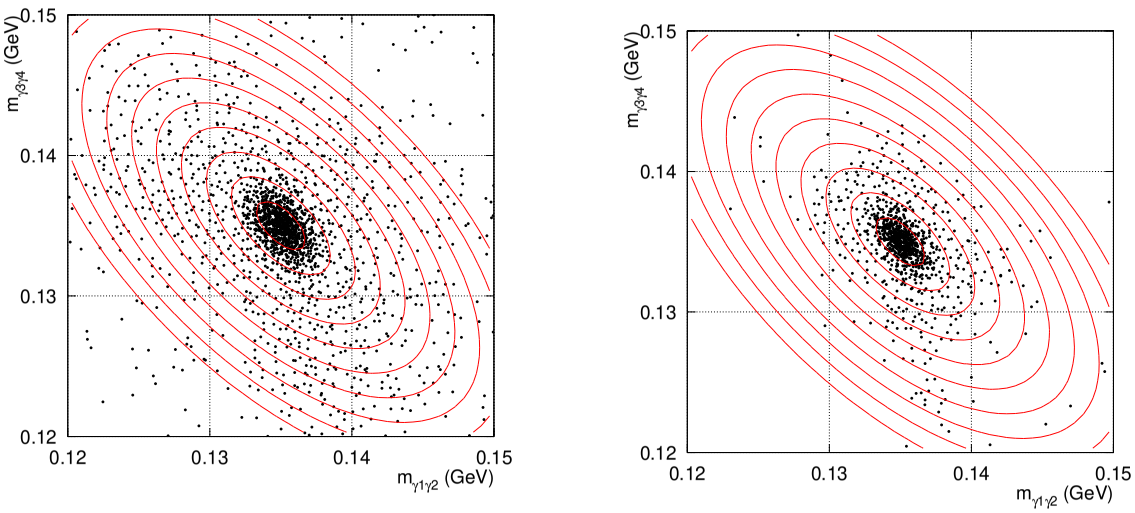
$5 \rightarrow 100$ GeV : linear within ~ 0.2 %.



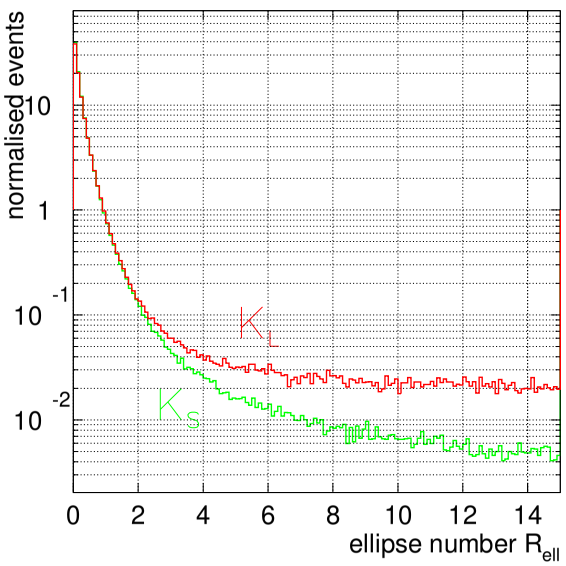
$$\frac{\sigma(E)}{E} = \frac{3.5\%}{\sqrt{E}} \oplus \frac{110MeV}{E} \oplus 0.6\%$$

Neutral Background

K_L K_S



$$R_{ell} \equiv \frac{1}{9}\left\{\left(\frac{\frac{m_1+m_2}{2}-m_{\pi^0}}{\sigma_{\frac{m_1+m2}{2}}}\right)^2+\left(\frac{\frac{m_1-m_2}{2}}{\sigma_{\frac{m_1-m2}{2}}}\right)^2\right\}$$



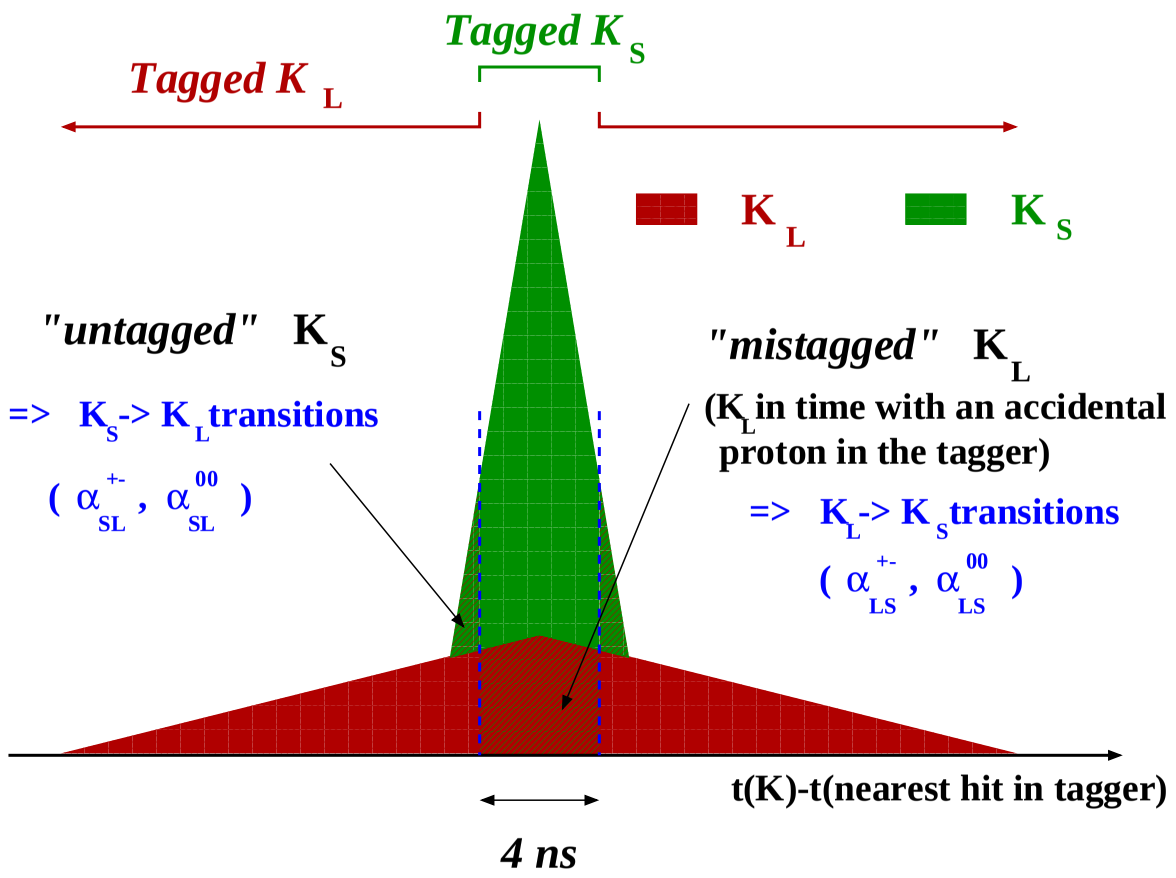
Signal region : $R_{ell} < 1.5$

Background level

not weighted $\sim 3.10^{-3}$

weighted $\lesssim 1.10^{-3}$

Tagging : Principle

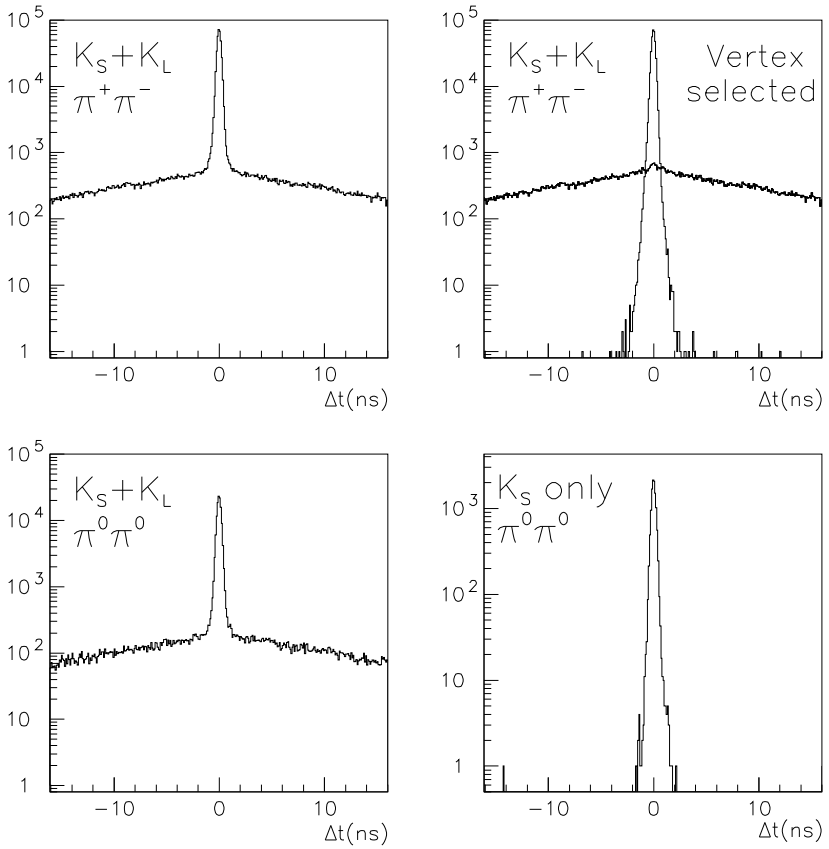


- $K_L \rightarrow K_S$ transitions "dilute" the value of R

- Significant errors on the double ratio R only if large differences between charged and neutral decays e.g.

$$\Delta(\alpha_{LS}{}^{00} - \alpha_{LS}{}^{+-}) = 5 \times 10^{-4} \Rightarrow \Delta(\mathrm{Re}(\varepsilon'/\varepsilon)\ ) \simeq 1.5 \times 10^{-4}$$

Tagging : Measurements



❖ Charged mode : K_L and K_S are well distinguished by their reconstructed vertex.

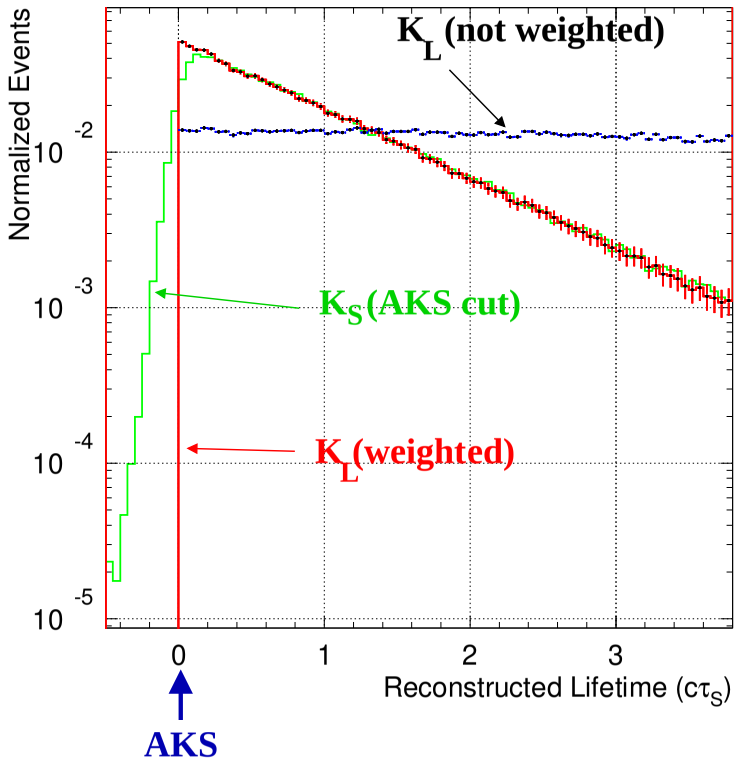
$$\alpha_{SL}{}^{+-} \sim (1.4 \pm 0.1) \times 10^{-4}$$
$$\alpha_{LS}{}^{+-} \sim (11.20 \pm 0.03)\ \%$$

❖ $(\alpha_{LS}{}^{00} - \alpha_{LS}{}^{+-})$ is measured with a 5.10^{-4} accuracy by shifting the coincidence window out of time.

❖ $\alpha_{SL}{}^{00}$ computed using $K_S \rightarrow \pi^0 e^+ e^- \gamma$ and γ conversions
Limited statistics ⇒ dominant tagging uncertainty

❖ Total error from tagging on $\mathrm{Re}(\varepsilon'/\varepsilon) \lesssim 2.10^{-4}$ (dominated by statistic of data used to check tagger performances)

Lifetime weighting



- Weighting ⇒ similar z vertex distributions K_S -vs- K_L
  - reduce acceptance corrections to less than .5 %
  - cost : increase of the statistical error (up to 40 % with $c\tau < 4c\tau_S$)

- Use of AKS counter gives a precise determination of the beginning of the fiducial volume for K_S decays.

⇒ reduces significantly double ratio sensitivity to distance scale

Energy Scale

- Neutral energy scale $\Leftrightarrow$ Distance scale (via K mass constraint) and vertex definition.

- To ensure that there is no effect on the double ratio, the average Neutral distance scale should be known to $\approx$ few $\times 10^{-4}$

- The energy scale can be adjusted in the data by fitting the AKS position which sharply defines the beginning of the K_S decay region independently of the reconstructed energies.

- Stability of the energy scale with time $\approx \pm\ 5.10^{-4}$ peak to peak (variations can be corrected using the method above).

- Special runs (with π^- beam and thin target producing π^0 and η of known origin) are used to cross-check energy scale and systematic effects.

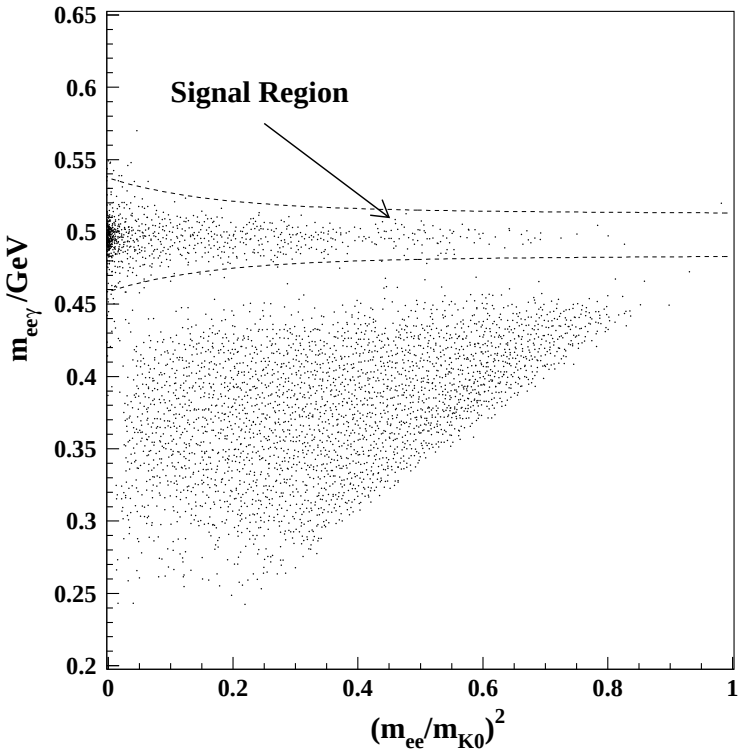
Other sources of systematics

- Differential K_L -K_S accidental activity
  - studied by overlaying random events
- Acceptance corrections (slight difference in Kl and Ks beam shapes) : using MC simulations

Conclusions from '97 data

- ε'/ε analysis well advanced.
- Thorough systematics studies of the stability of the measurement on various cuts and running conditions underway
- Expect ε'/ε value from '97 data with an accuracy comparable to previous experiments

Preliminary: $K_L \to e^+e^-\gamma$



- Measurement of the **BR** and α_{K^*} determining the structure of the $K \to \gamma^*\gamma$ vertex
- Signal/Background = 6864/10 events
- Preliminary **BR** $= (1.06 \pm 0.022_{stat} \pm 0.020_{sys.}) \times 10^{-5}$
- Preliminary $\alpha_{K^*} = -0.357 \pm 0.060$

The 1998 Run

Improvements

- replacement of all HV blocking capacitors of LKr calorimeter

$\Rightarrow$ stable operation at 3 kV

- New carbon-fibre beam pipe

$\Rightarrow$ $\sim$ 30 % reduction of current in the drift chambers

- Level 2 charged trigger upgrade : 200 MHz processors

$\Rightarrow$ higher input rates

$\Rightarrow$ more complex algorithm (e.g. 4 track trigger)

- Commissioning of a new DAQ system : Event-builder PC farm

$\Rightarrow$ sustained transfer rate of 20 Mbytes/s

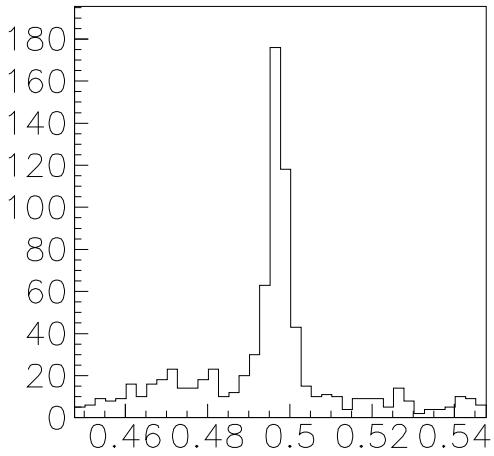
$\Rightarrow$ $\sim$ 30 % trigger rate increase

Achievements

- took data from mid-May until September
- $\sim 2\ 10^6\ K_L \rightarrow \pi^0\pi^0$
- 75 Tbytes of data recorded and reprocessed
- Analysis of 98 data starting

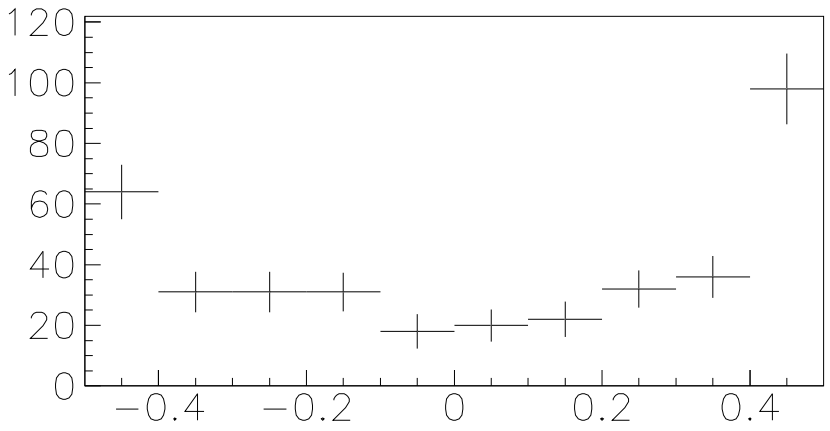
Preliminary: $K_L \to \pi^+\pi^-e^+e^-$

- Expect large ($\approx 14\%$) asymmetry in the angle between the (π^+,π^-) and (e^+,e^-) planes, violating CP and T (indirect CP $\Leftrightarrow \epsilon$), observed by KTeV
- In 98, collected data with a 4 track trigger to study this decay mode
- Main background $K_{\mathrm{L}} \to \pi^+\pi^-\pi^0{}_D$ with missing γ



$\approx \frac{2}{3}$ of 98 statistics $\to \approx$ 380 signal events with a background of $\approx$ 70 events.
Preliminary BR $= (3.13 \pm 0.23(stat)) \times 10^{-7}$
(systematic error estimation in progress)

Preliminary: $K_L \to \pi^+\pi^-e^+e^-$



cos(ϕ)sin(ϕ)

- **raw** Distribution of cos(ϕ)sin(ϕ)
- ϕ is the angle between the $(\pi^+ - \pi^-)$ and the (e^+e^-) decay planes
- The above distribution is not corrected for acceptance

Conclusions

- ε'/ε analysis on 97 data still in progress.
- $\approx$ 3 times more data have been recorded in 98
- The 98 data has been reprocessed and the analysis is in a starting phase
- Higher statistics in 98 will allow to complement the systematic checks from 97 data
- Data taking for ε'/ε will continue in 1999 and 2000 ($\sim$ 120 days/year) to achieve a precision of 2×10^{-4}