Status of $Re(\varepsilon\prime/\varepsilon)$ measurement at the NA48 experiment

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☞ on behalf of the **NA48 COLLABORATION**:
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Outline

- The experiment
  - Method
  - Beams
  - Detectors
  - Triggers
  - Analysis recipes
- 1997 Data
  - $\mathrm{K_S}$ Tagging
  - $K_{\mathrm{L,S}} \longrightarrow \pi^+\pi^-$
    events selection, background
  - $K_{\mathrm{L,S}} \longrightarrow \pi^0\pi^0$
    events selection, background
- 1998 Data
  - Improvements
  - Overview
- Conclusions

Introduction

☞NA48 aim :

Determine the direct CP violation parameter $\mathrm{Re}(\varepsilon'/\varepsilon)$ in the Kaon system with an accuracy of 2×10^{-4}

☞Previous precision measurements results for $\mathrm{Re}(\varepsilon'/\varepsilon)$:

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

Experimental strategy

☞ Measure the Double Ratio :

$$R = \frac{\Gamma(K_L \to \pi^0\pi^0)}{\Gamma(K_S \to \pi^0\pi^0)} \Big/ \frac{\Gamma(K_L \to \pi^+\pi^-)}{\Gamma(K_S \to \pi^+\pi^-)}$$

$$\approx 1 - 6 \times \mathrm{Re}(\varepsilon'/\varepsilon)$$

☞ Collect $> 10^6 K_L \to \pi^0\pi^0$ (limiting mode)

☞ Minimal corrections

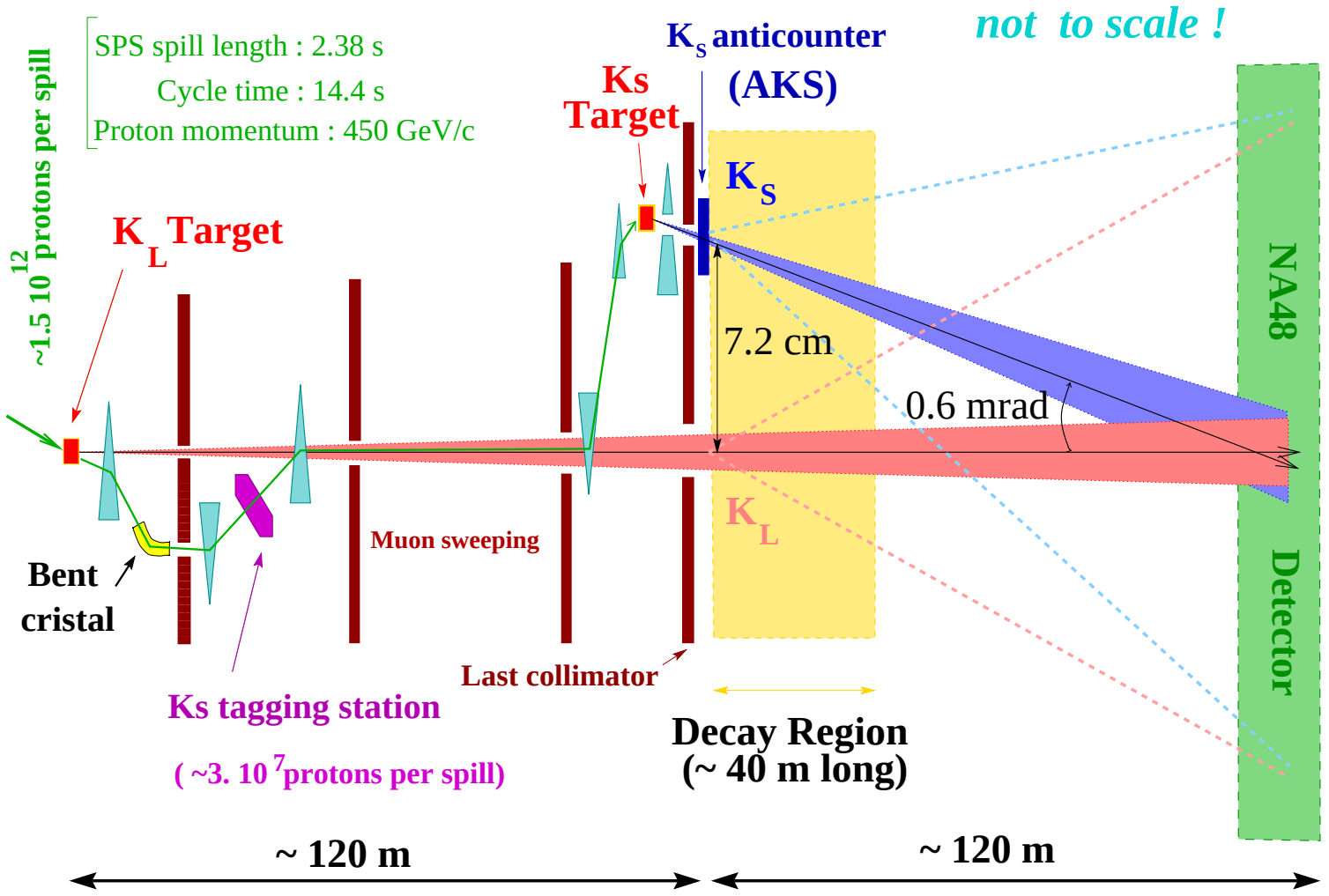
$\Rightarrow$ 4 modes measured

- Concurrently
- In the same fiducial volume + analysis in momentum bins and lifetime weighting of KL

  $\Rightarrow$ minimise acceptance corrections
- With an apparatus based on
  - magnetic spectrometer ($\pi^+\pi^-$ mode)
  - liquid Krypton homogeneous calorimeter ($\pi^0\pi^0$ mode)

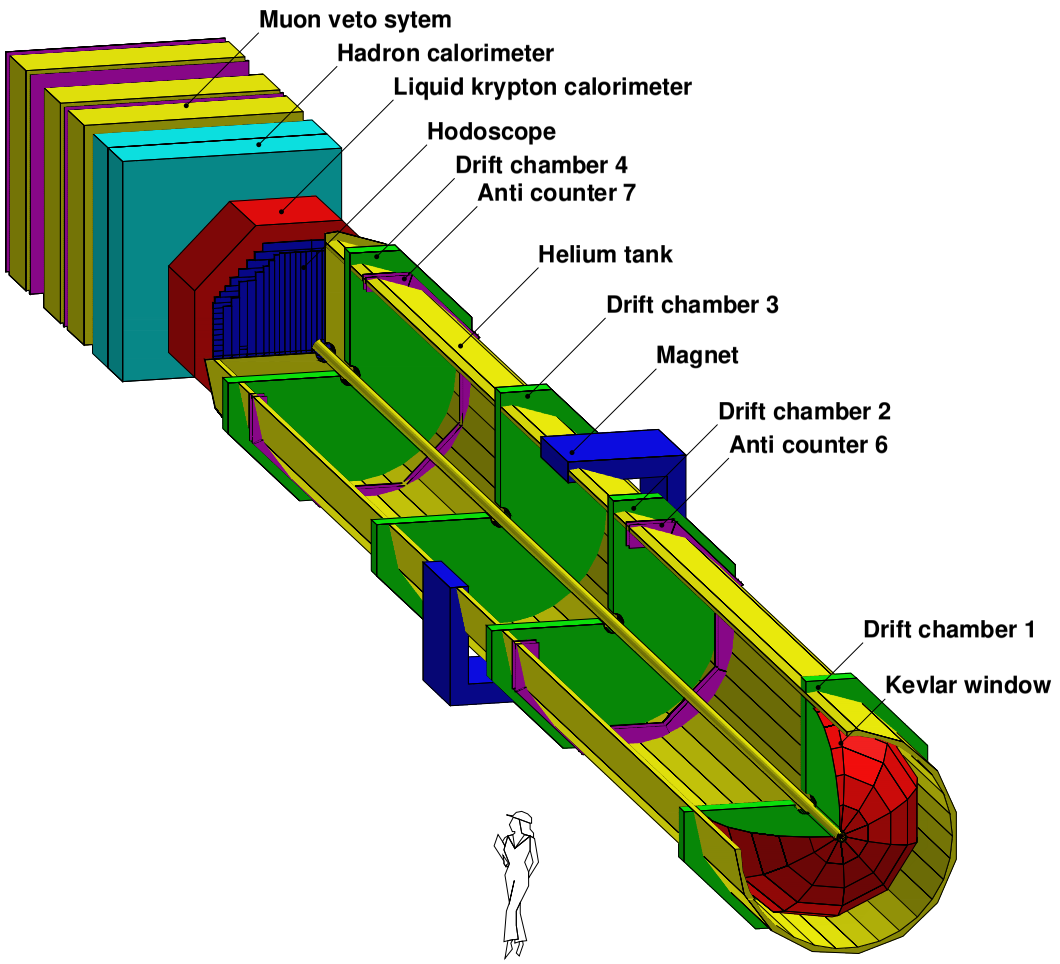
  $\Rightarrow$ good resolutions and small background levels

Simultaneous K_S and K_L Beams



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

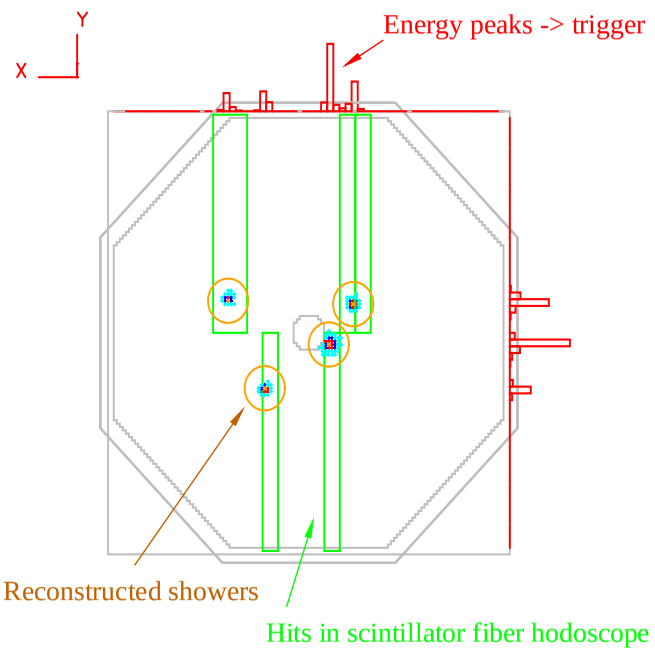
Detector



- ☞ $K_{L,S} \to \pi^+\pi^-$
  - magnetic spectrometer (P$_\perp$ kick $\sim 256 MeV/c$)
  - scintillator hodoscope for the event time
- ☞ $K_{L,S} \to \pi^0\pi^0$
  - quasi-homogeneous Liquid Kr calorimeter :
    - high granularity (13212 $2 \times 2cm^2$ cells)
    - projective geometry
- ☞ muon counters for $K_{\mu 3}$ background

Neutral Trigger

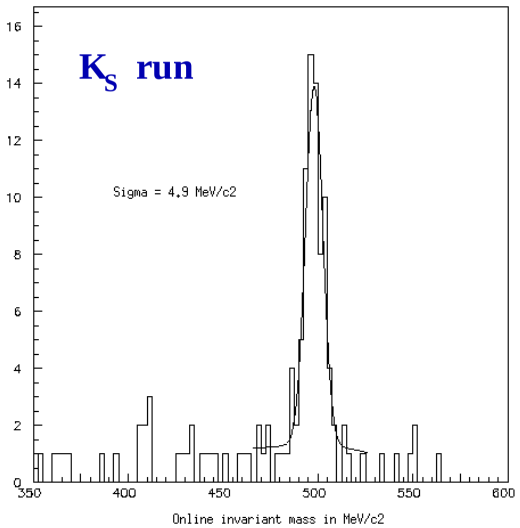
- Fully pipelined software trigger based on the calorimeter cells information.
  - Reduce the information of the calorimeter to 64 vertical and 64 horizontal projections.
  - Compute and cut on :
    - number of in time clusters per projection
    - total energy in the calorimeters
    - decay vertex position



- Run 1997 :
  - $\mathrm{K_L}$ decay rate in the detector ~ 500kHz
  - Trigger output rate ~ 2 kHz
  - Dead-time negligible
  - Efficiency $\simeq 99.9$ %

Charged Trigger

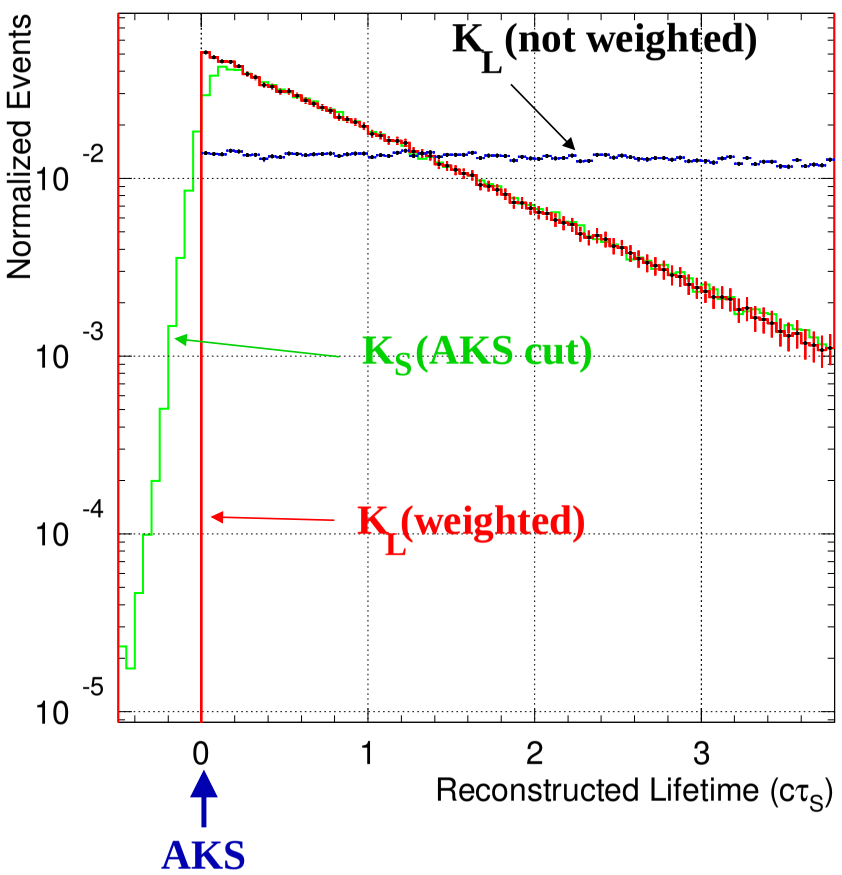
- Level 1 : Hodoscope and Total energy in calorimeters
- Level 2 : Fast tracking in the spectrometer
  - hardware coordinate builder
  - farm of processors : reconstruction of vertex and mass



- Run 1997
  - Typical trigger input rates
    L1 : $\sim$ 500kHz L2 : $\sim$ 70kHz
  - L2 rejection factor : $\sim$ 50
  - Dead time $\sim$ 1 %
    (applied in the analysis to neutrals)
  - Combined $L1 \cdot L2$ efficiency :
    - K_S : $(90.61 \pm 0.08)\%$
    - K_L : $(90.66 \pm 0.10)\%$

Analysis recipes

- R computation in momentum bins
  - gain : reduce acceptance corrections
- Lifetime weighting of KL
  $\Rightarrow$ similar z vertex distributions $\mathrm{K_S}$ -vs- $\mathrm{K_L}$
  - gain : reduce acceptance corrections
  - loss : increase of the statistical error



Analysis recipes

- Hardware upstream cut on KS (using AKS anticounter)
  - gain : reduce sensitivity of R on Z scale

- Absolute neutral energy scale fixed fitting AKS position
  - reconstructed z_{vertex} is proportional to E_{kaon} (from momentum conservation and K mass constraint)

- Differential $\mathrm{K_L}$ -$\mathrm{K_S}$ accidental activity studied by overlaying random events

- Residual acceptance corrections ($\sim .5\%$) computed with MC

The 1997 Run

Sept-Oct 1997 : first $\mathrm{Re}(\varepsilon'/\varepsilon)$ run

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

- 2/3 of nominal beam intensity
- 42 days of data taking

$\Downarrow$

25 Tbytes of data written on tape
Read-out 80 Mbytes/s
$\sim$ 12 K events recorded per spill

$\Downarrow$

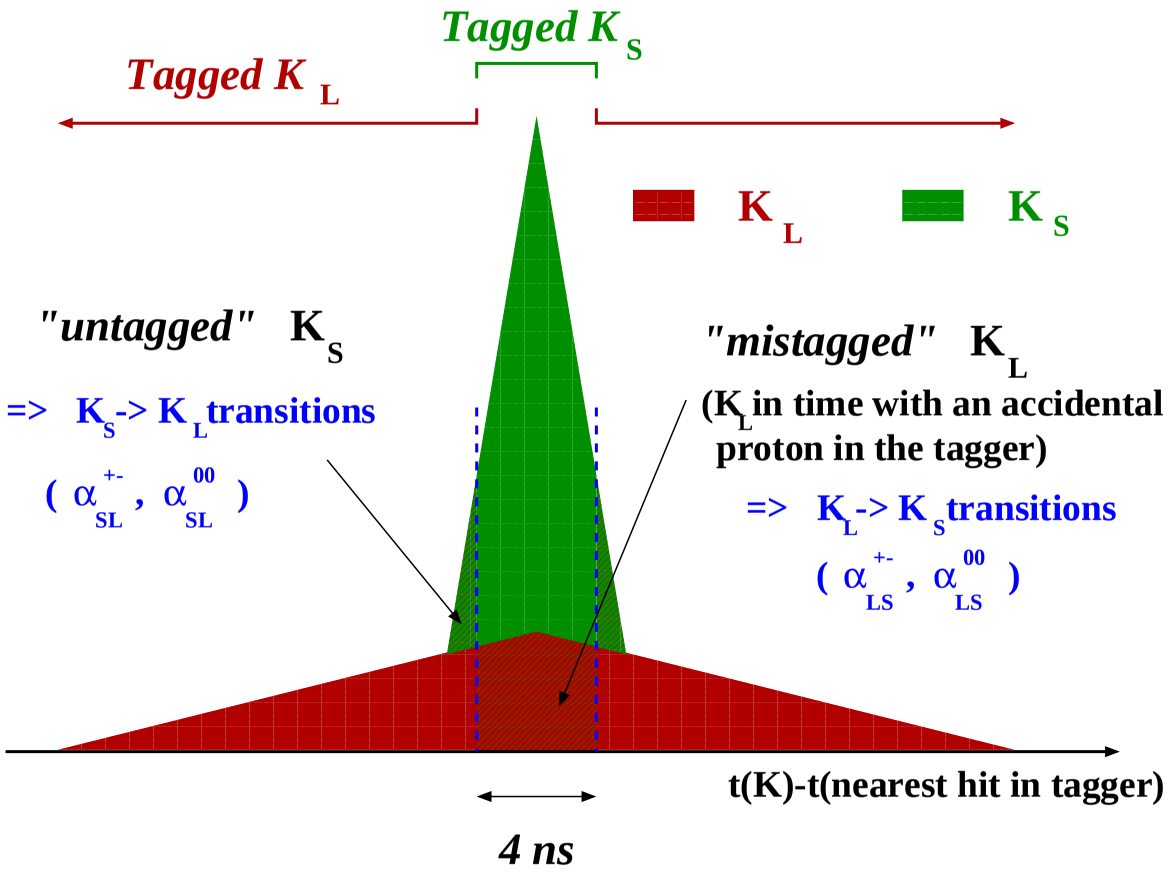
$\sim$ 650 000 $\mathrm{K_L} \rightarrow \pi^0\pi^0$

with

$70\ \mathrm{GeV} < E_K < 170\ \mathrm{GeV}$

$0 < \tau < 4.0\ \tau_S$

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.

$$\Delta(\alpha_{LS}{}^{00} - \alpha_{LS}{}^{+-}) = 5 \times 10^{-4}$$

$$\Downarrow$$

$$\Delta(\mathrm{Re}(\varepsilon'/\varepsilon)\ ) \simeq 1.5 \times 10^{-4}$$

Tagging : Measurements

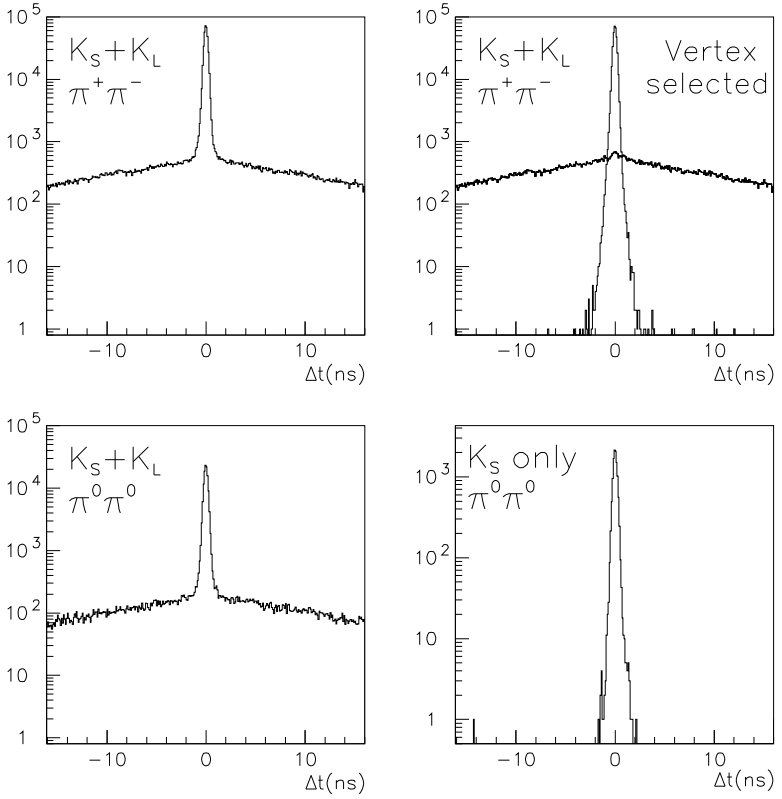
☞Charged mode :

$\mathrm{K_L}$ and $\mathrm{K_S}$ well distinguished by reconstructed vertex.

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

☞Neutral mode :

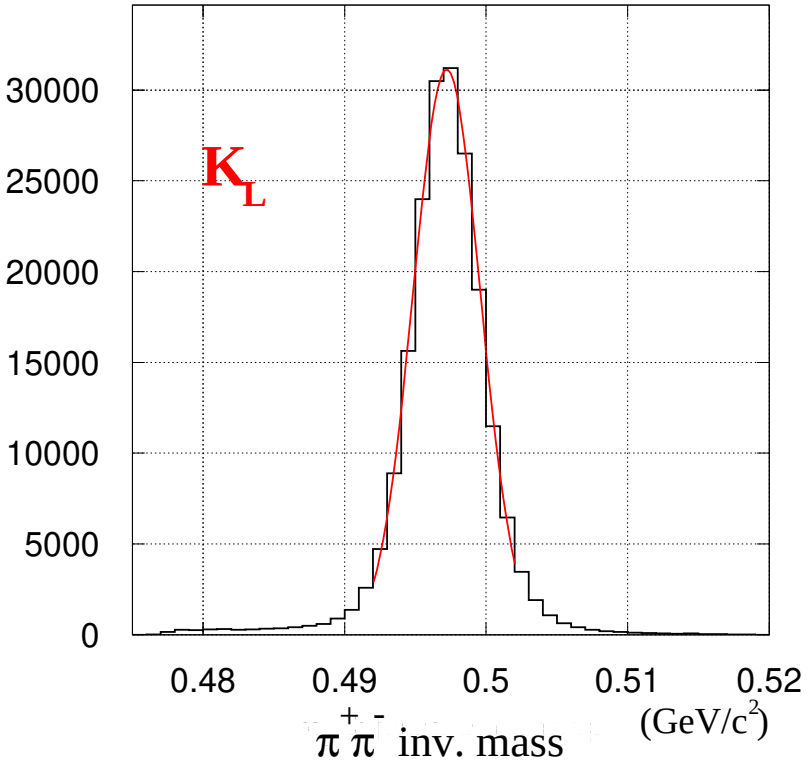
- $({\alpha_{LS}}^{00} - {\alpha_{LS}}^{+-})$ measured with side bands of tagging window ($5 \cdot 10^{-4}$ accuracy)
- ${\alpha_{SL}}^{00}$ computed with $\mathrm{K_S} \rightarrow \pi^0 e^+ e^- \gamma$ and γ conversions in kevlar window.

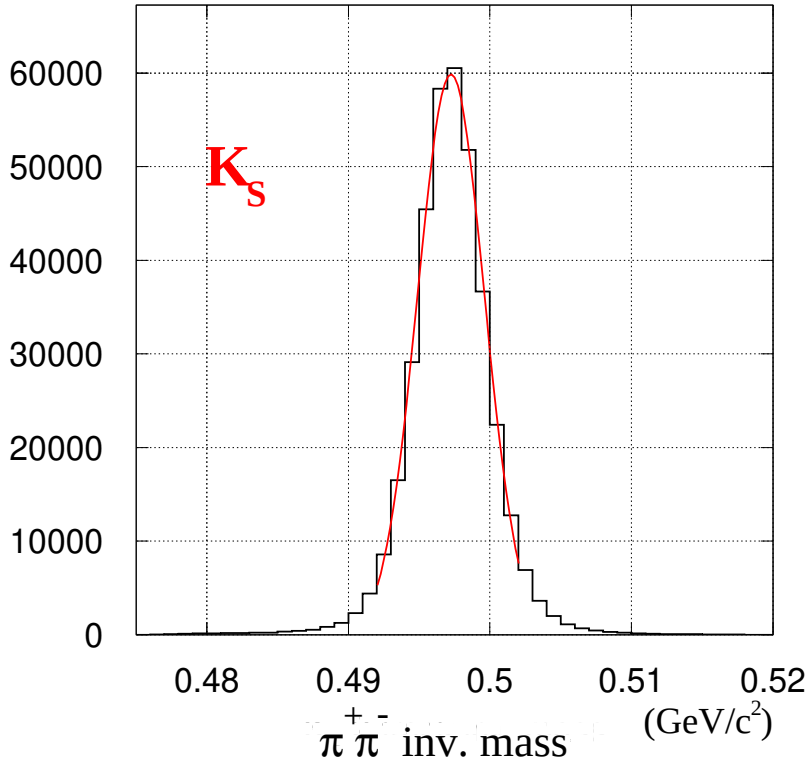


☞Error from tagging on $\mathrm{Re}(\varepsilon'/\varepsilon) \lesssim 2.10^{-4}$ (mainly of statistical nature)

Limited statistics for ${\alpha_{SL}}^{00}$ measurement is dominant tagging uncertainty

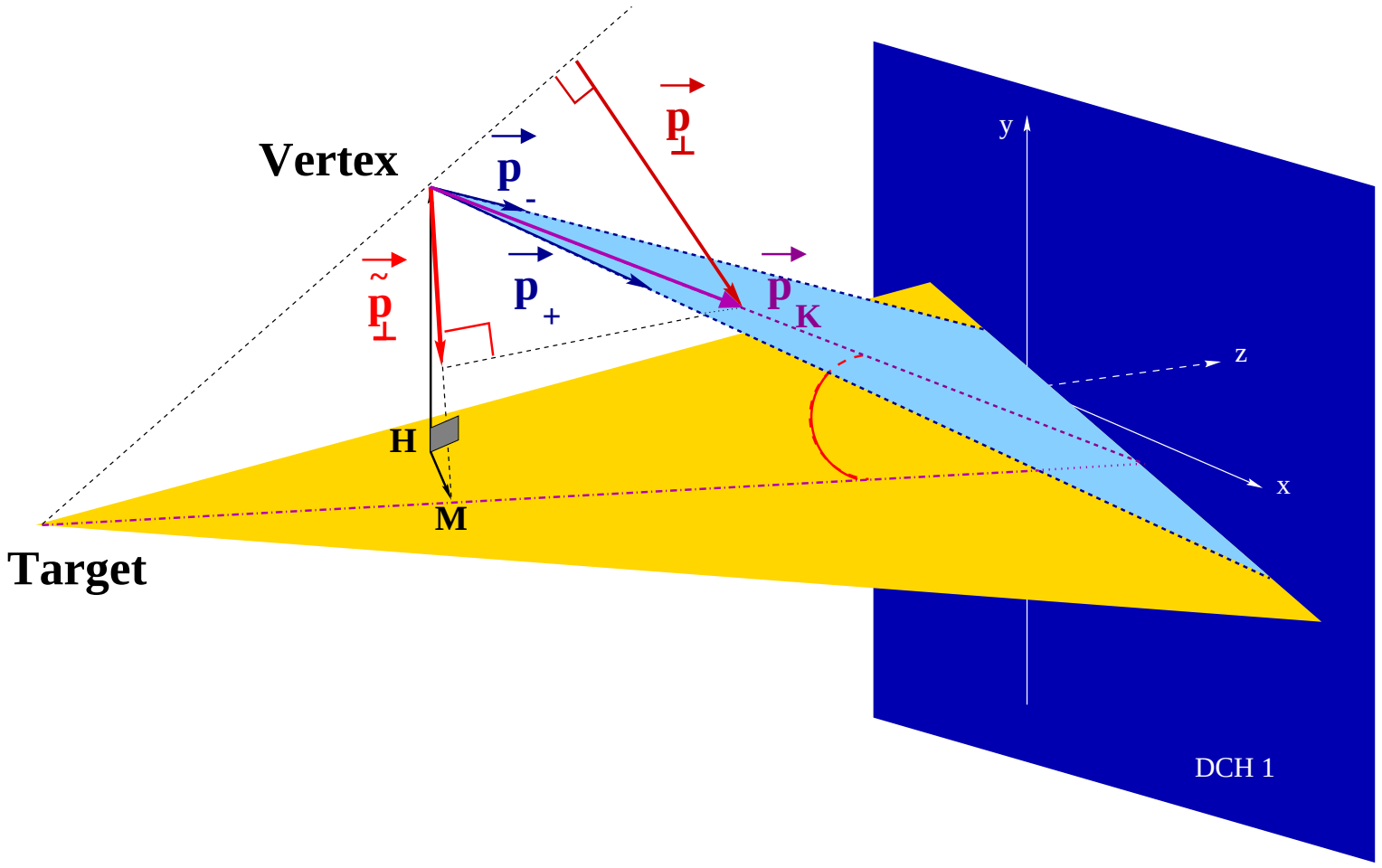
$K_{L,S} \to \pi^+\pi^-$: Spectrometer performance





- Mass resolution : ~ 2.5 MeV/c^2
- $\dfrac{\sigma(\mathrm{P})}{\mathrm{P}} = 0.48\,\% \oplus 0.009\ \mathrm{P[GeV/c^2]}\,\%$
  (from e^- scan at 25 and 100 GeV)

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

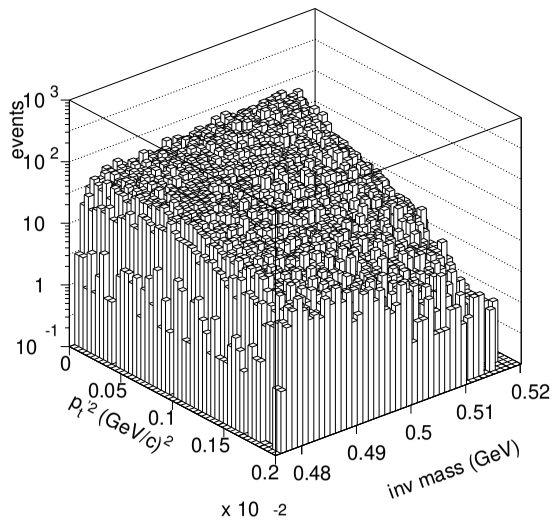


☞ Different target positions $\Rightarrow$ $P_\perp{}^2$ very different for K_S and K_L .

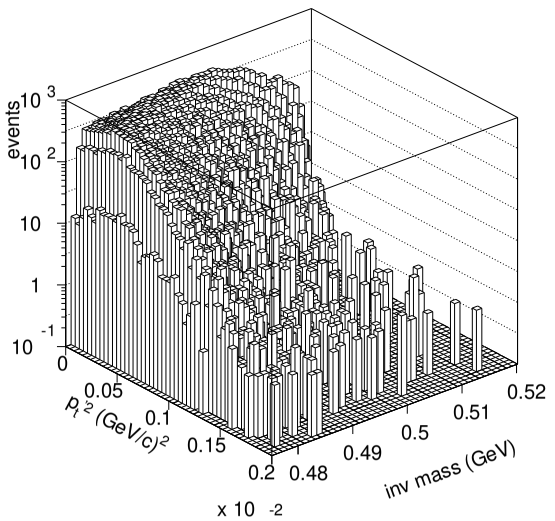
☞ $\tilde{P}_\perp{}^2$: more suitable variable

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

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

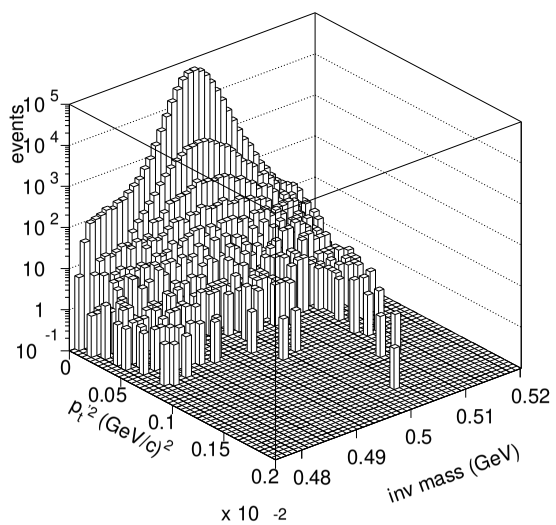


Identified K_{e3} (E/P)

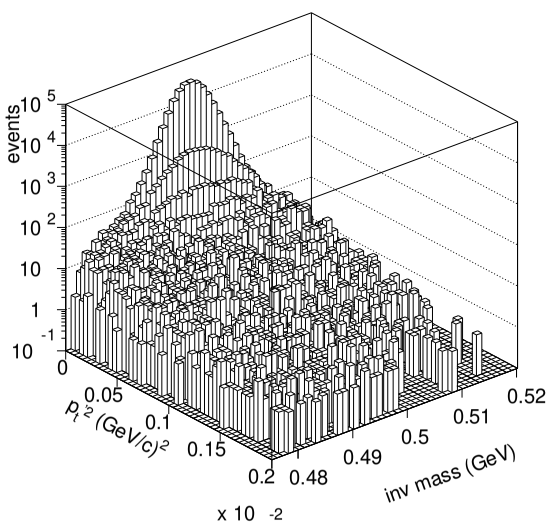


Identified $K_{\mu 3}$ (μ vetos)

☞ Background shape is evaluated in mass vs $P_\perp{}^2$ plane with selected samples of K_{e3} and $K_{\mu 3}$.



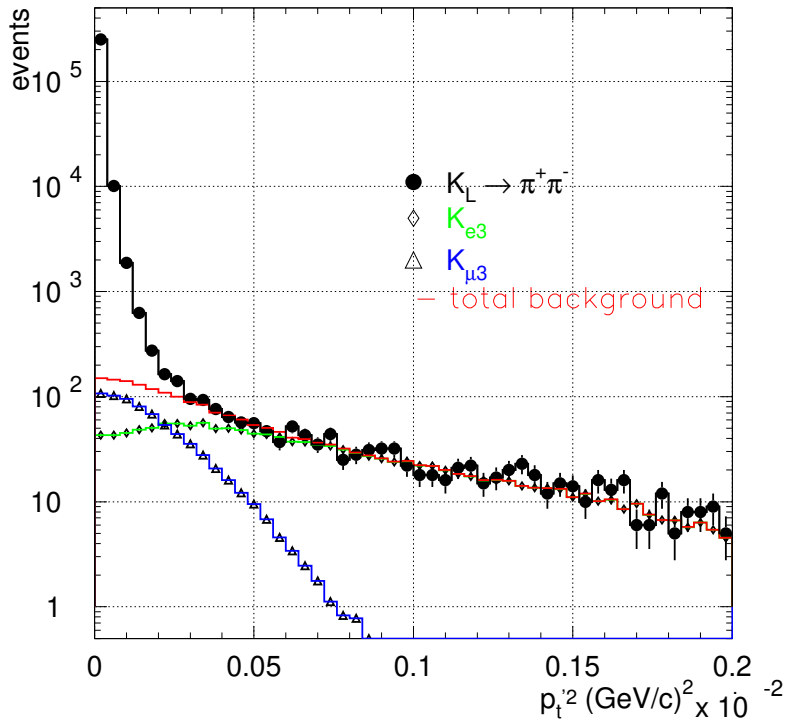
$K_S \to \pi^+\pi^-$



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

☞ The amount of remaining background is evaluated in control regions and extrapolated to the signal region.

Charged Background : Estimation

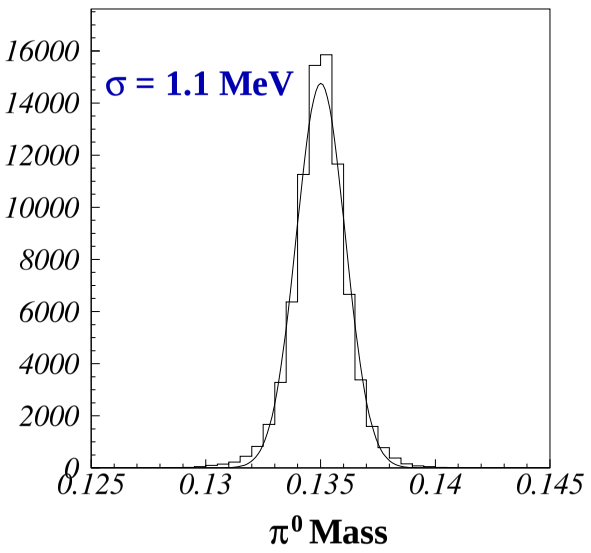


☞ Charged background kept at the $\lesssim 0.3\%$ level

The e.m. Calorimeter

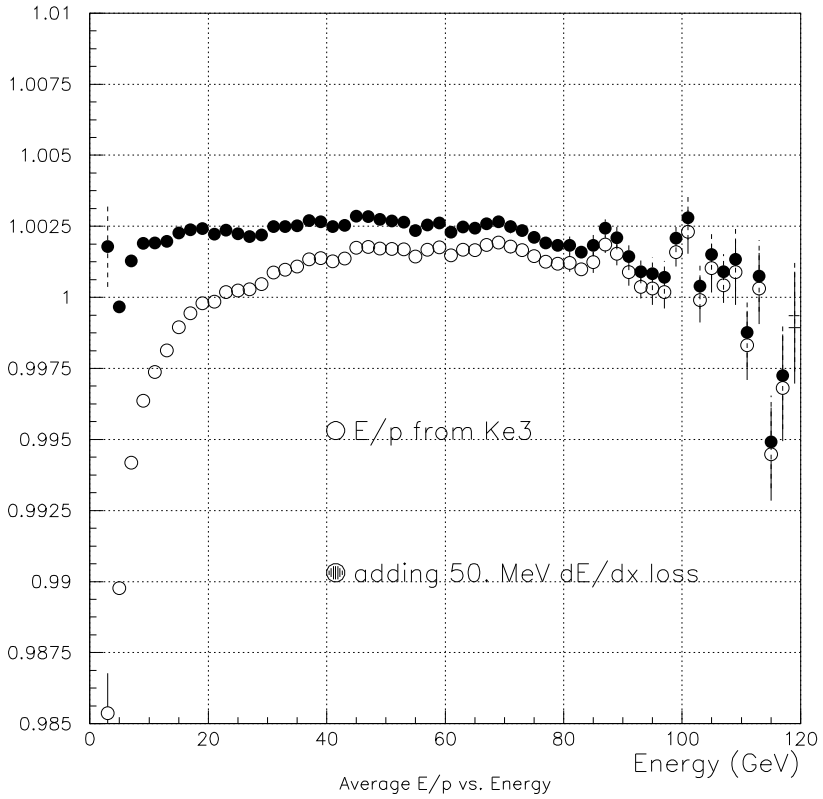
- Operation :
  - reduced HV (1.5 kV) due to capacitor problem
    $\Rightarrow$ $\sim 20\%$ increase in the electronic noise
    $\Rightarrow$ small space charge effect ($< 0.5\%$)
  - One column (4 cm wide) not connected to HV
- Calibration :
  - Electronics gain checked regularly
  - 1 correction factor based on K_{e3} per cell to improve resolution
- Reconstruction algorithm :

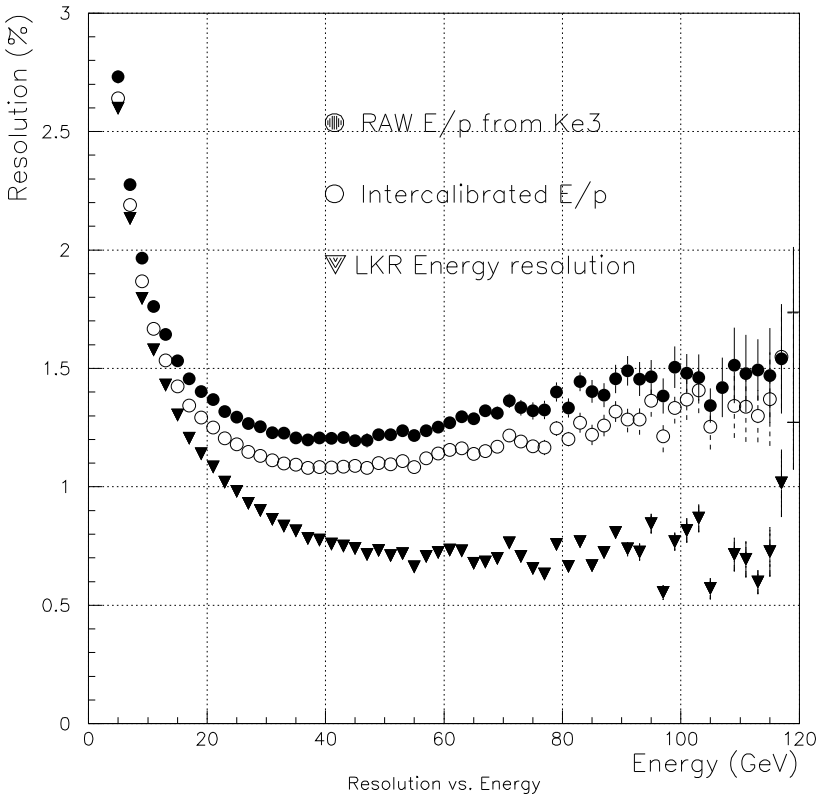
  $K_{\mathrm{L,S}} \rightarrow 2\pi^0 \rightarrow 4\gamma$
  - Vertex position reconstruction imposing the Kaon mass
  - Pairing the photons to get the best π^0 combination



The e.m. Calorimeter : Linearity and Resolution

With electrons from K_{e3}



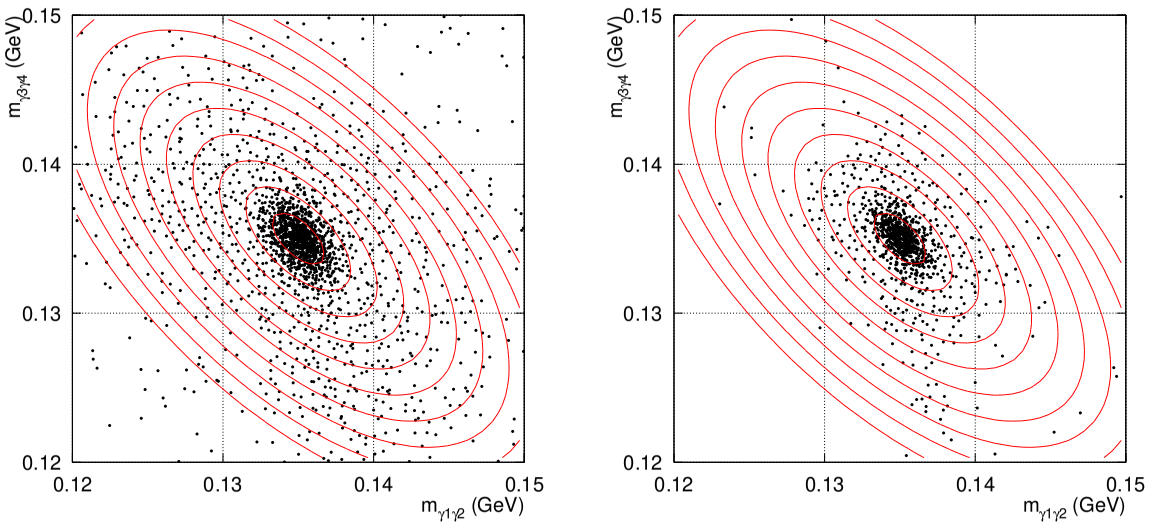


$5 \rightarrow 100$ GeV :
linear within ~ 0.2 %.

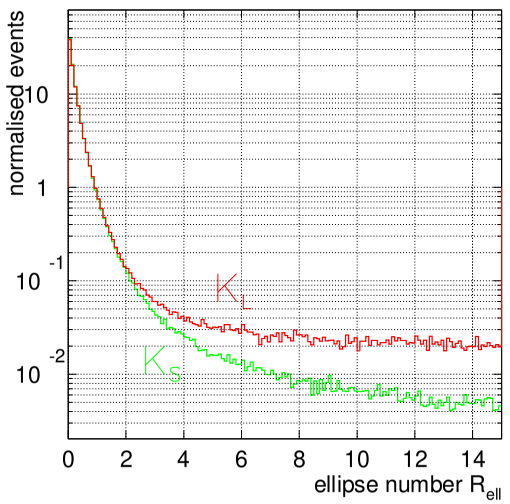
$$\frac{\sigma(E)}{E} = \frac{3.5\%}{\sqrt{E}} \oplus \frac{110MeV}{E} \oplus 0.6\%$$

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 :

- unweighted $\sim 3 \cdot 10^{-3}$
- weighted $\lesssim 1 \cdot 10^{-3}$

Conclusions from 1997 data

- ☞ ε'/ε analysis is well advanced.
- ☞ Thorough systematic studies underway.
  In particular we are studying the sensitivity of our measurement to various cuts and running conditions.

- Expect ε'/ε value from '97 data with an accuracy comparable to previous experiments.

The 1998 Run

☞ Improvements

- replacement of all HV blocking capacitors of LKr calorimeter

⇒ stable operation at 3 kV

- New carbon-fiber beam pipe

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

- Level 2 charged trigger upgrade : 200 MHz processors

⇒ higher input rates

⇒ more complex algorithm (e.g. 4 track trigger)

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

⇒ sustained transfer rate of 20 Mbytes/s

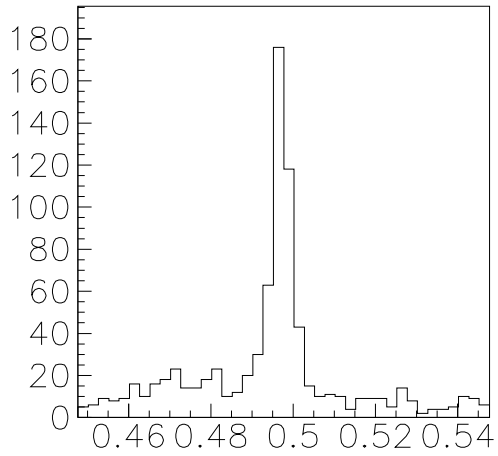
⇒ $\sim$ 30 % trigger rate increase

☞ Achievements

- mid-May to September data taking run
- $\sim 2\ 10^6\ \mathrm{K_L} \rightarrow \pi^0\pi^0$ collected
- 75 Tbytes of data recorded and reprocessed

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

- 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 tracks trigger to study this decay mode
- Main background $K_{\rm L} \to \pi^+\pi^-\pi^0{}_D$ with missing γ



$M_{\pi^+\pi^-{\rm e}^+{\rm e}^-}(GeV)$

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

Conclusions

- ε'/ε analysis on 97 data is well advanced.
- $\approx$ 3 times more data has been recorded in 98.
- 98 data has been processed.
- ε'/ε analysis on 98 data is starting now.
- The higher statistics of 98 data will allow us to complement systematic checks.
- Data taking for ε'/ε will continue in 1999 and 2000
  $\Rightarrow$ ($\sim$ 120 days/year) to achieve a accuracy of 2×10^{-4}