NA48 : direct CP violation in K^0 decays

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Workshop on CP violation in K
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High Energy Accelerator Research Organization

❖ 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 measurement
  - Method
  - Beams
  - Detectors
  - Triggers
- 1997 Data Taking
  - $\mathrm{K_S}$ Tagging
  - $K_{\mathrm{L,S}} \rightarrow \pi^+\pi^-$
  - $K_{\mathrm{L,S}} \rightarrow \pi^0\pi^0$
  - Lifetime weighting and fiducial volume definition
- 1998 Data Taking
  - Improvement
  - Overview
- Prospects and conclusions

Introduction

NA48 aim : Determine the direct CP violation parameter
$\mathrm{Re}(\varepsilon'/\varepsilon)$ in the Kaon system
$\rightarrow$ reach an accuracy of 2×10^{-4}

Previous precision measurements are :

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

Double ratio technique :

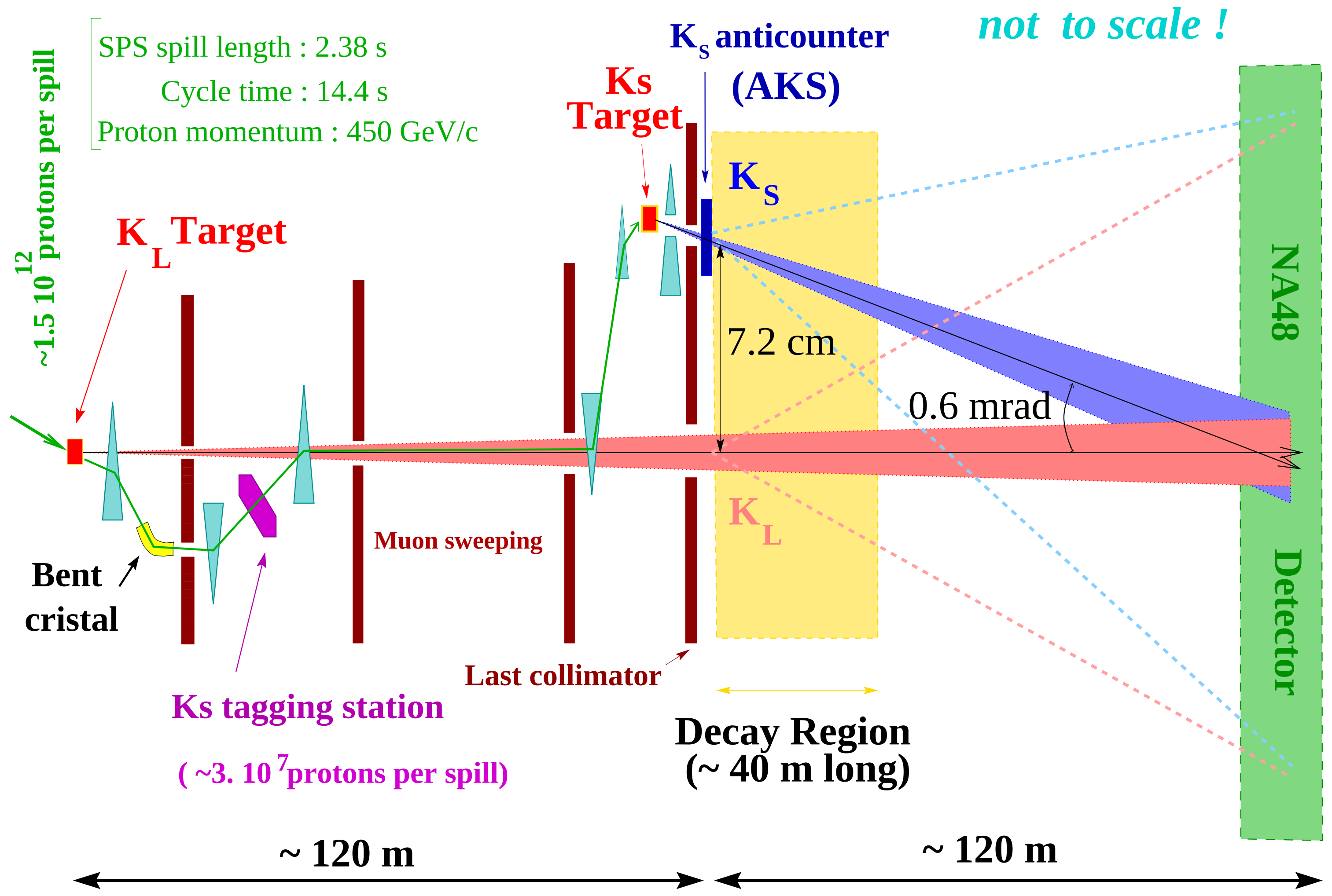
$$\mathrm{R} = \frac{\Gamma(\mathrm{K_L} \rightarrow \pi^0\pi^0)}{\Gamma(\mathrm{K_S} \rightarrow \pi^0\pi^0)} \Big/ \frac{\Gamma(\mathrm{K_L} \rightarrow \pi^+\pi^-)}{\Gamma(\mathrm{K_S} \rightarrow \pi^+\pi^-)} \approx 1 - 6 \times \mathrm{Re}(\varepsilon'/\varepsilon)$$

- Collect *several* 10^6 $\mathrm{K_L} \rightarrow \pi^0\pi^0$ (limiting mode)
- Minimal corrections $\rightarrow$ the 4 modes are measured

$$\left\{ \begin{array}{l} \text{simultaneously} \\ \text{from the same fiducial volume} \\ \text{with efficient } \mathrm{K_S}\text{-}\mathrm{K_L} \text{ blind triggers} \\ \text{with a magnetic spectrometer } (\pi^+\pi^-) \text{ and} \\ \text{a Liquid Krypton e.m. calorimeter } (\pi^0\pi^0) \end{array} \right.$$

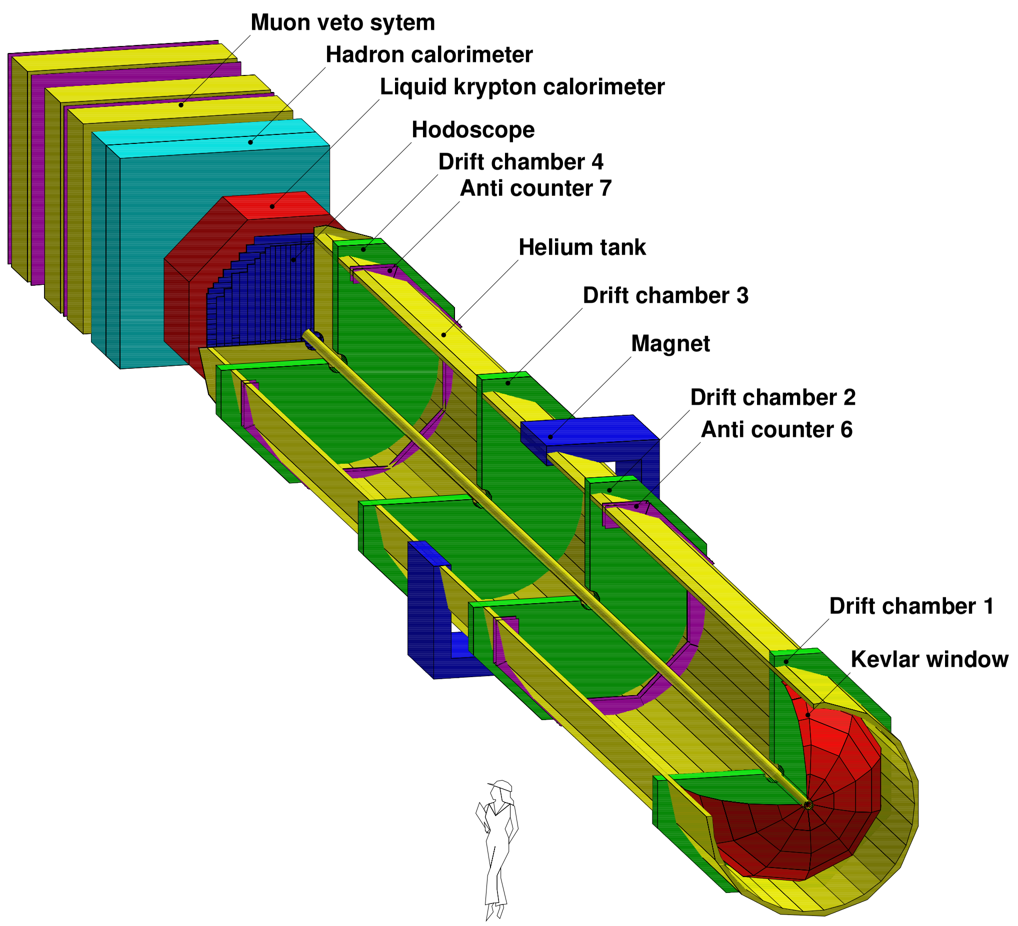
+ lifetime weighting of $\mathrm{K_L}$
$\Rightarrow$ identical Z vertex distribution for $\mathrm{K_L}$ & $\mathrm{K_S}$

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

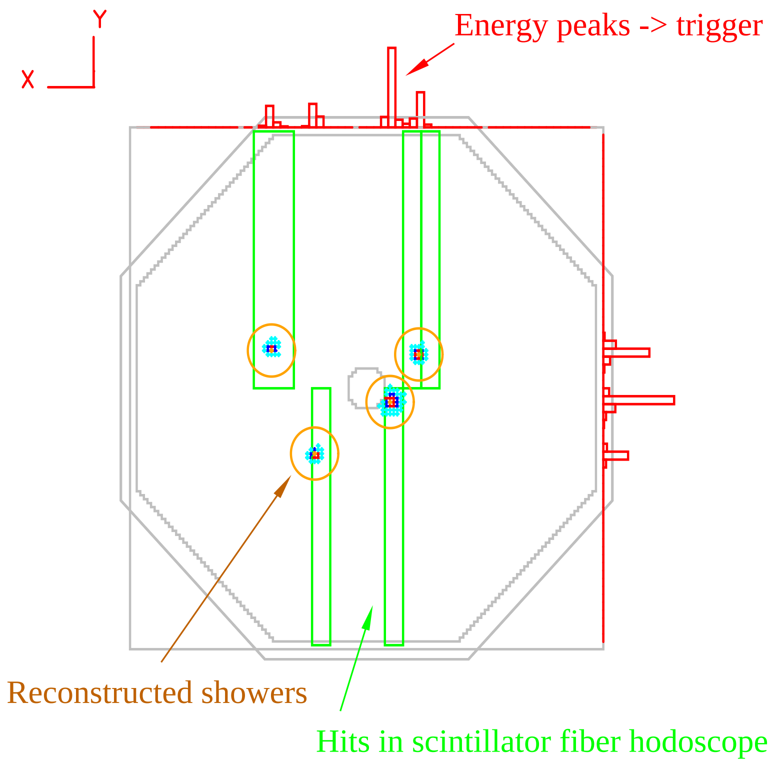


- $K_{\mathrm{L,S}} \to \pi^+\pi^-$
  - magnetic spectrometer ($\mathrm{P}_\perp{}^{kick} \sim 256MeV/c$)
  - event time measured with a scintillator hodoscope
- $K_{\mathrm{L,S}} \to \pi^0\pi^0$
  - quasi-homogeneous Liquid Krypton e.m. calorimeter :
    - high granularity (13212 $2 \times 2cm^2$ cells)
    - projective geometry
- muon counters for $\mathrm{K}_{\mu 3}$ background to $\mathrm{K_L} \to \pi^+\pi^-$

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 :

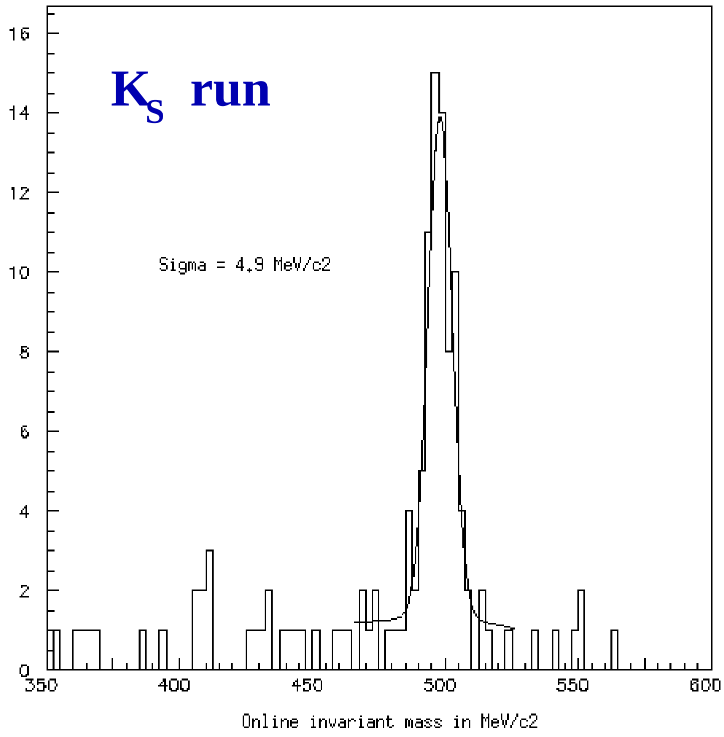
Input rate $\sim$ 1MHz (LKr activity)

Output rate $\sim$ 2 kHz

Efficiency $>$ 99 %

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
  - Input : $\sim$ 70KHz
  - Rejection factor :$\sim$ 50
  - Dead time $\sim$ 1 % (applied to neutral)
- Combined $L1 \cdot L2$ efficiency :
  - K_S : $(90.61 \pm 0.08)\%$
  - K_L : $(90.66 \pm 0.10)\%$

The 1997 Run

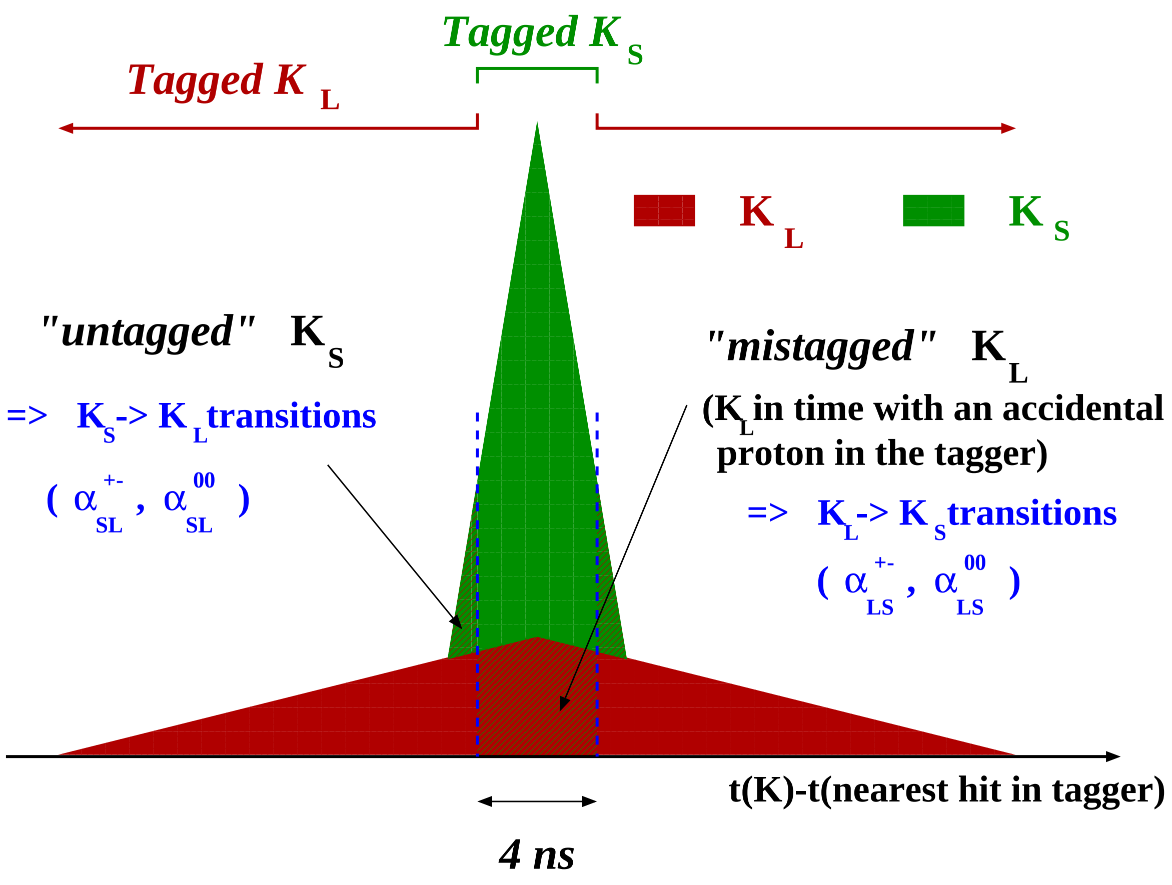
Sept/Oct 1997 : first $\mathrm{Re}(\varepsilon'/\varepsilon)$ run

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

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

$$\Rightarrow \sim 650\,000\ \mathrm{K_L} \rightarrow \pi^0\pi^0 \text{ with } \begin{cases} 70GeV < E_K < 170GeV \\ 0 < \tau < 3.5\tau_S \end{cases}$$

Tagging : Principle

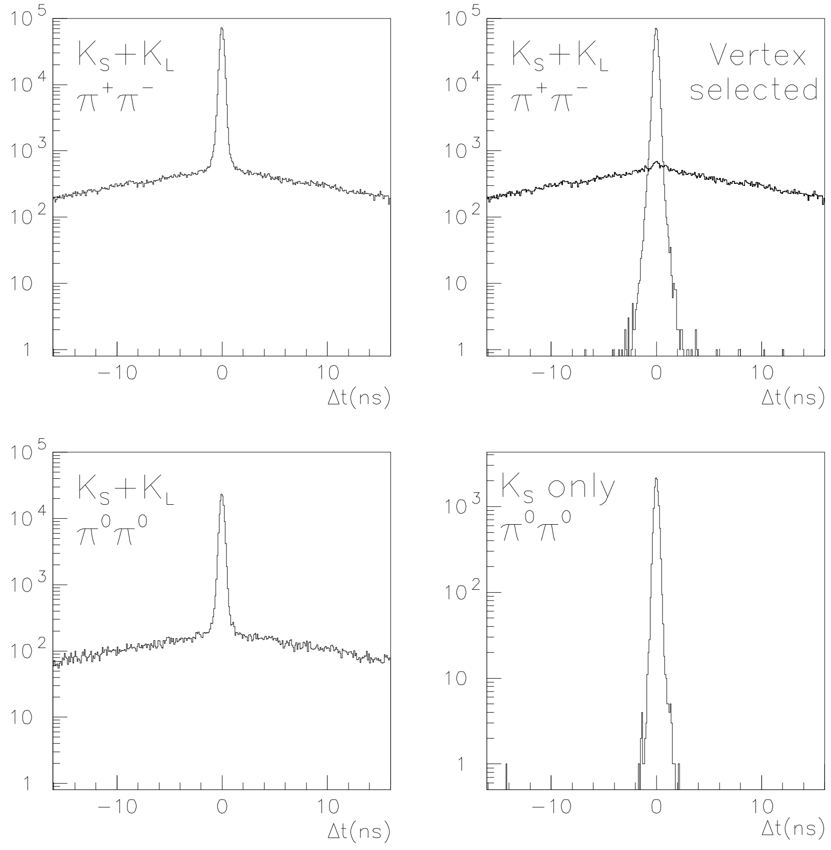


- $K_L \rightarrow K_S$ transitions “dilute” the value of R

- 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.

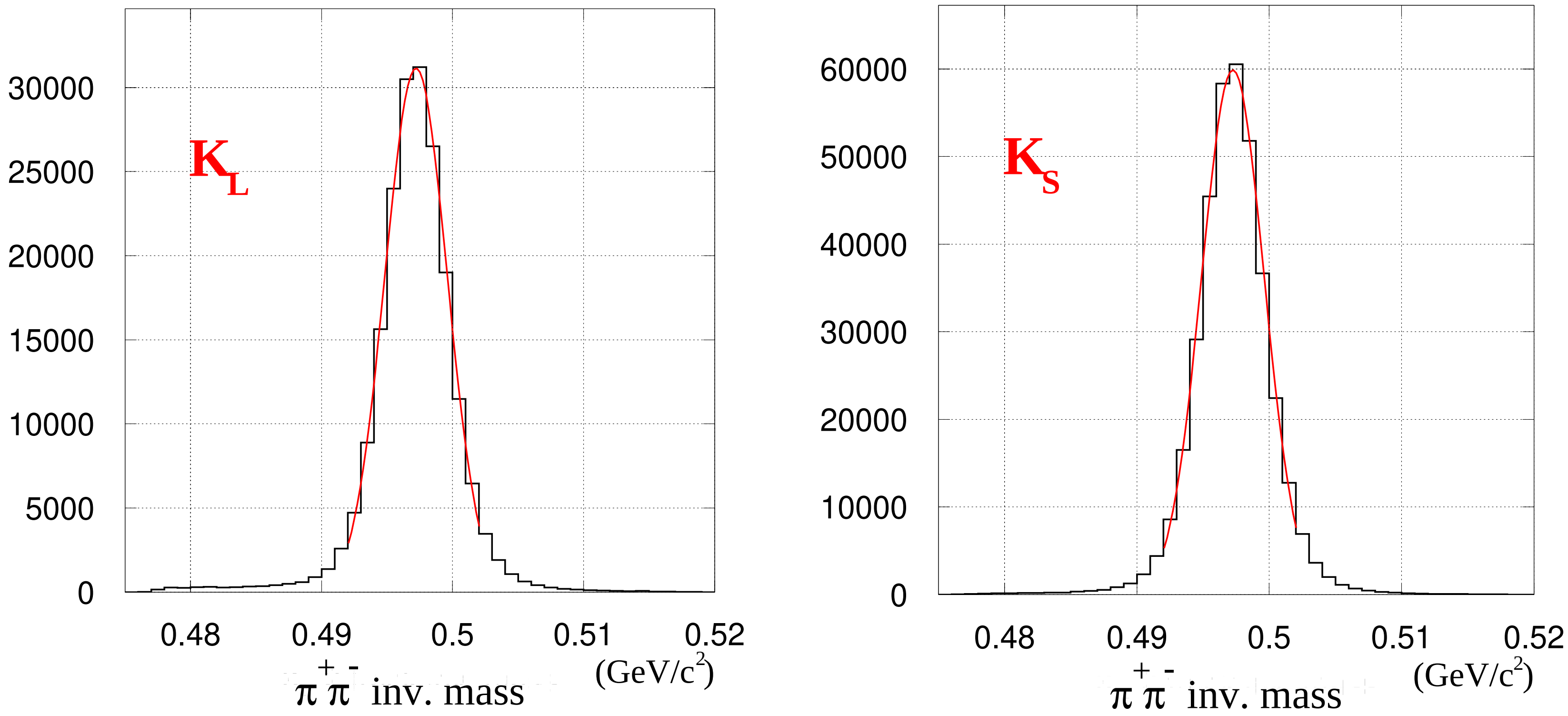
$$\alpha_{SL}{}^{+-} \sim (1.4 \pm 0.1) \times 10^{-4}$$
$$\alpha_{LS}{}^{+-} \sim (11.50 \pm 0.03)\ \%$$

❖ $(\alpha_{LS}{}^{00} - \alpha_{LS}{}^{+-})$ is measured with a 5.10^{-4} accuracy using side bands of tagging window.

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

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

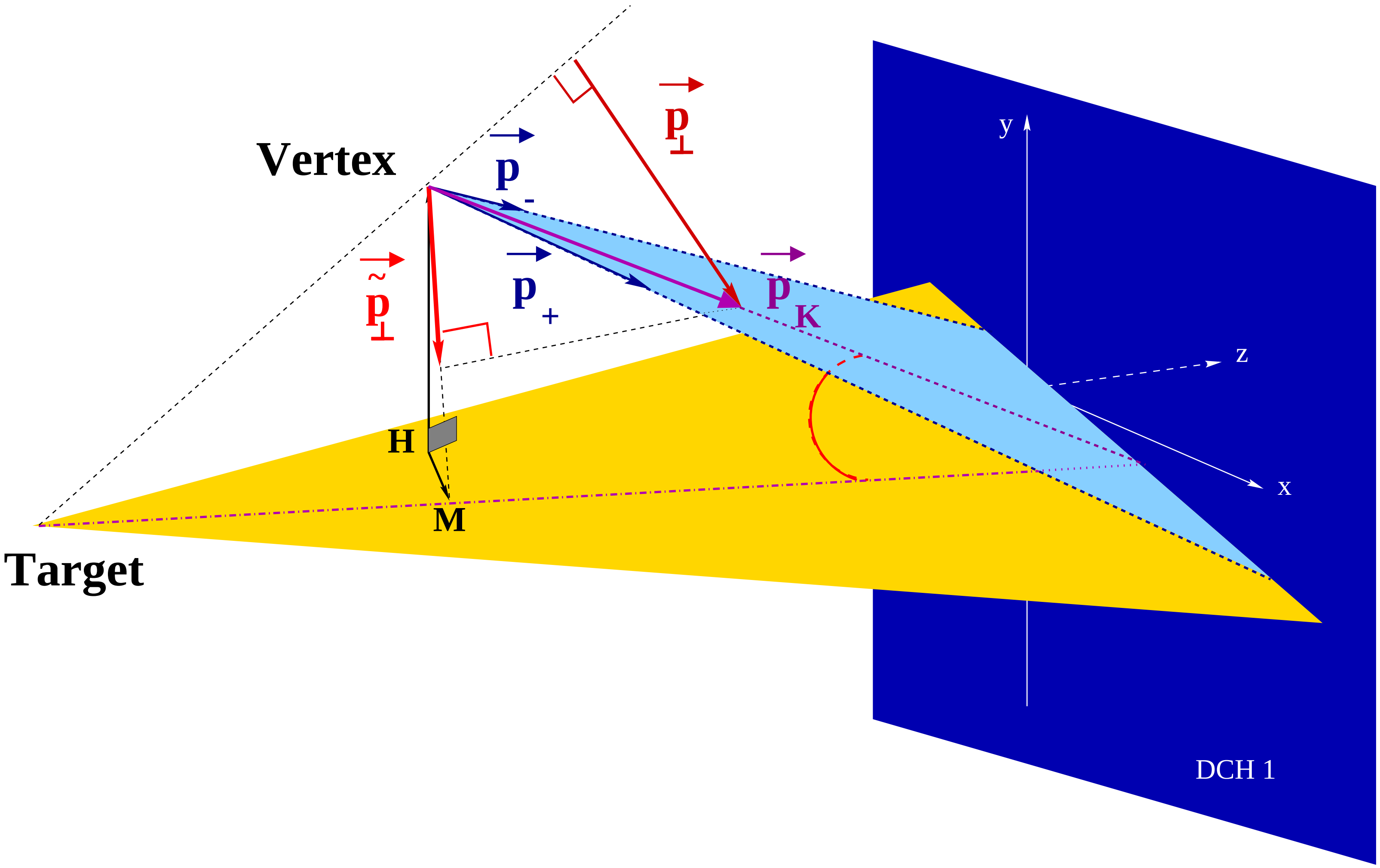
Mass resolution : ~ 2.5 MeV/c^2



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

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

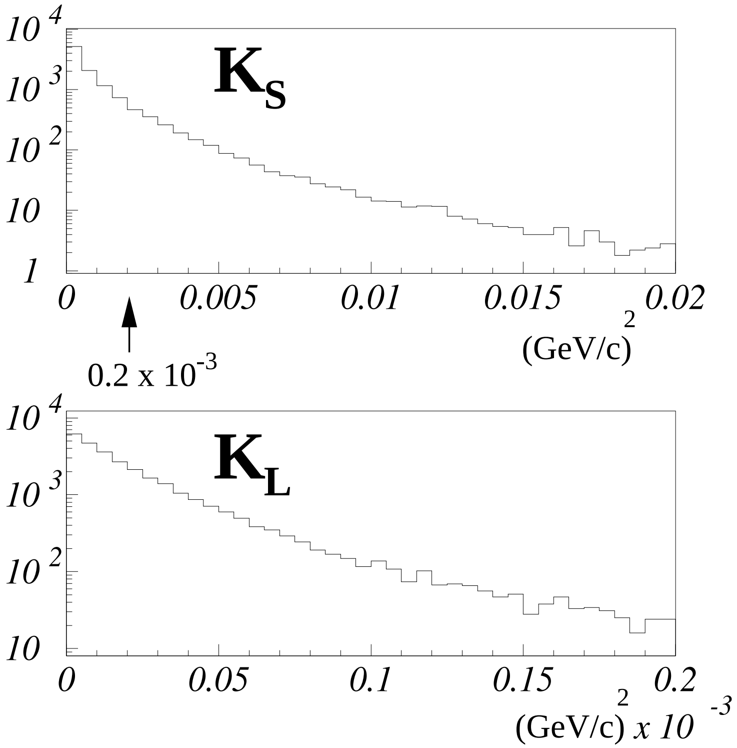
Charged Background : $P_\perp{}^2$



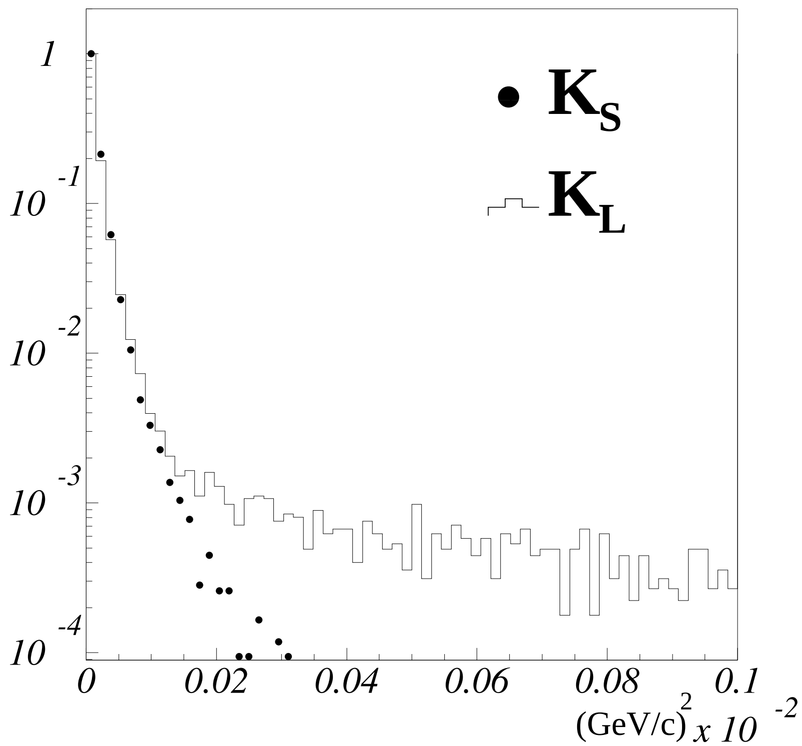
Because of the different target positions, $P_\perp{}^2$ is very different for K_S and K_L .

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

Charged Background : $P_\perp^2$



$P_\perp^2$

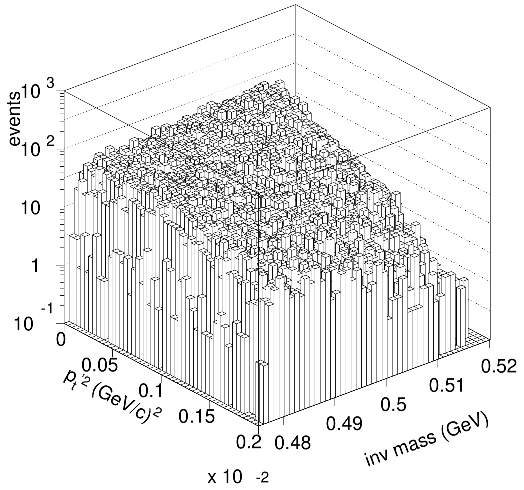


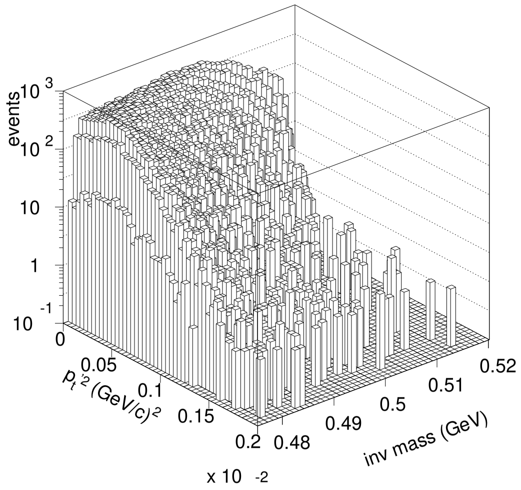
$\tilde{P}_\perp^2$

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

K_{e3} & $K_{\mu3}$ $\sim 10^2$ times more frequent than $K_L \to \pi^+\pi^-$

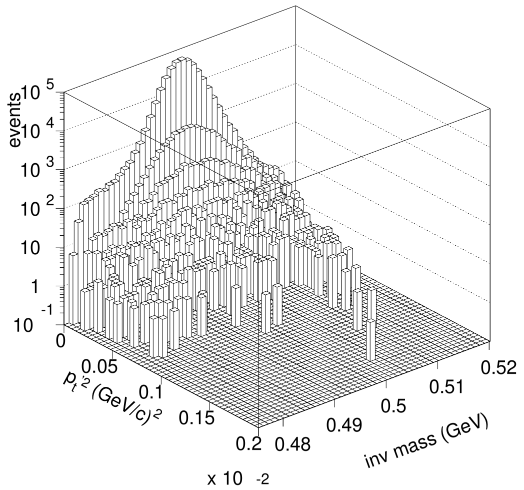
Identified K_{e3} (E/P) | Identified $K_{\mu3}$ (muon counters)

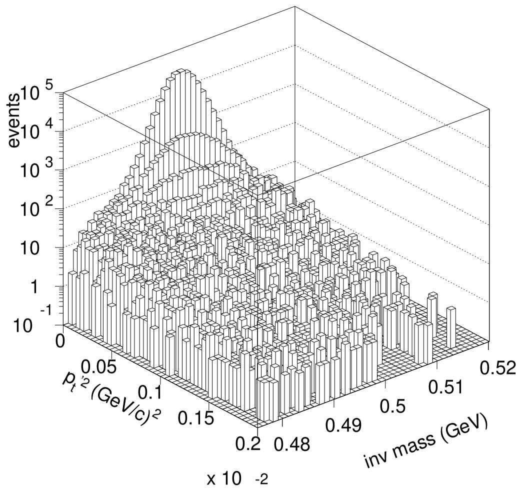




Shape of the background is evaluated in the mass vs $P_\perp{}^2$ plane with selected samples of K_{e3} and $K_{\mu3}$.

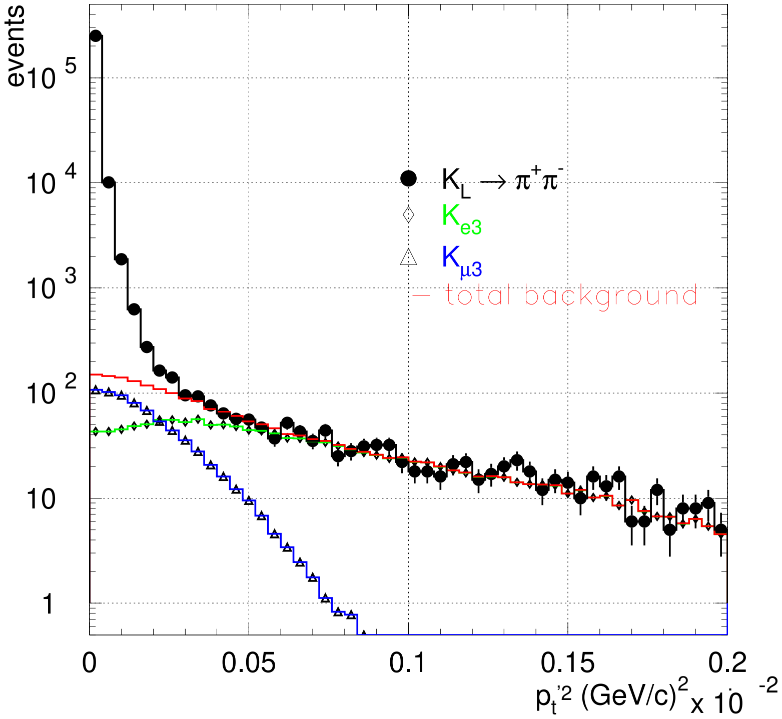
$K_S \to \pi^+\pi^-$ | $K_L \to \pi^+\pi^-$ (+ background)





The amount of remaining K_{e3} and $K_{\mu3}$ is then evaluated in control regions and extrapolated to the signal region.

Charged Background : Estimation



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

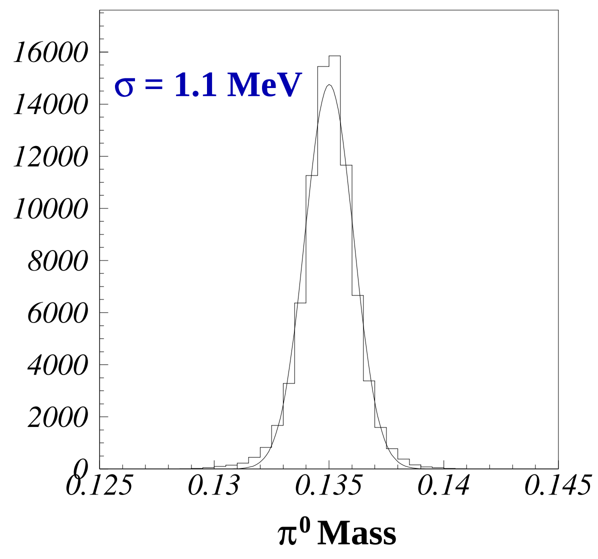
The e.m. Calorimeter

- 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

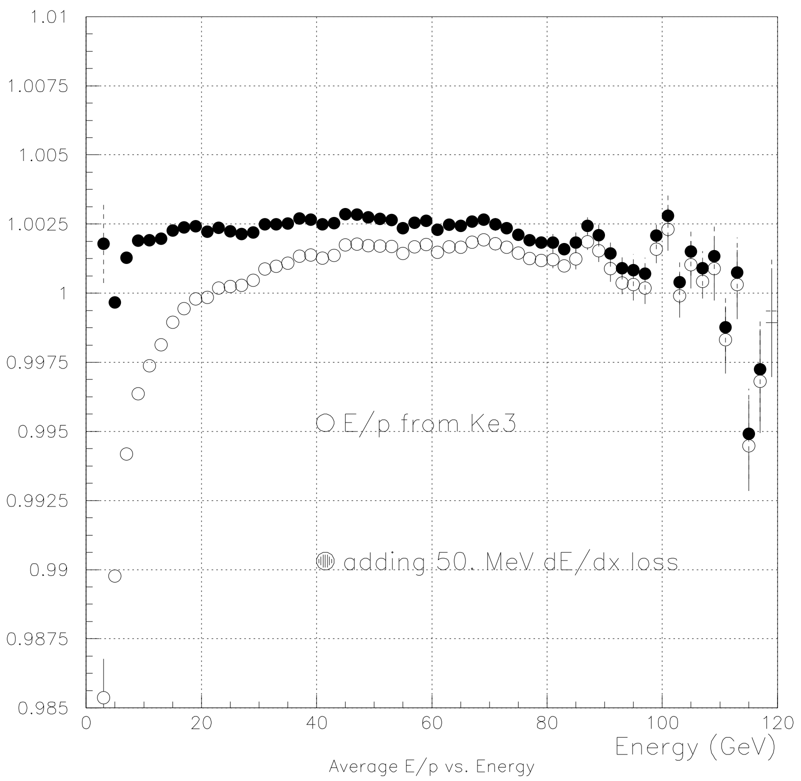
- Reconstruction

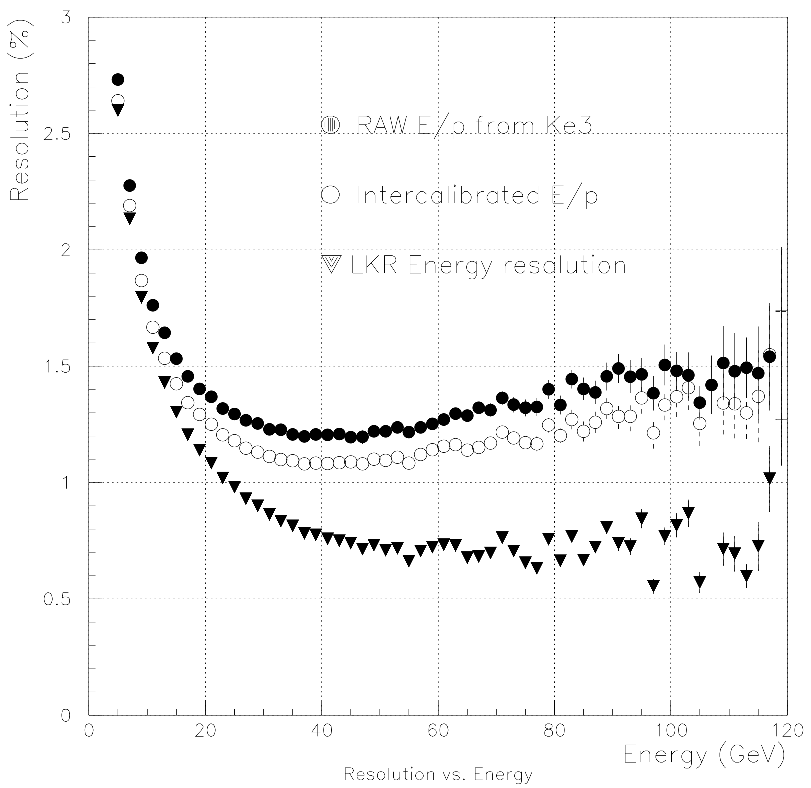
  $K_{L,S} \rightarrow 2\pi^0 \rightarrow 4\gamma$
  - ∗ Vertex position imposing the Kaon mass
  - ∗ Pairing the photons to get the best π^0 combination



Linearity and Resolution

With electrons from K_{e3}



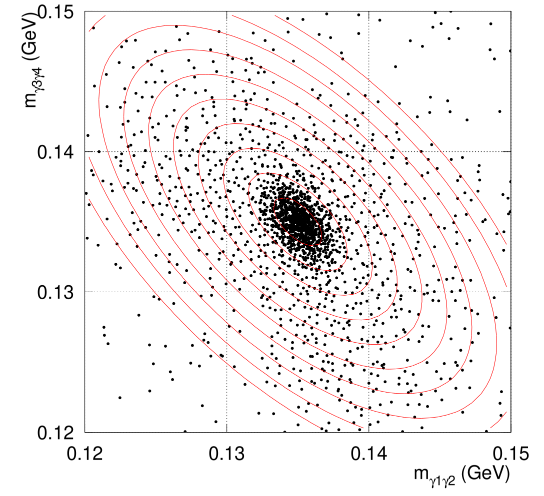


$5 \rightarrow 100$ GeV : linear whithin ~ 0.2 %.

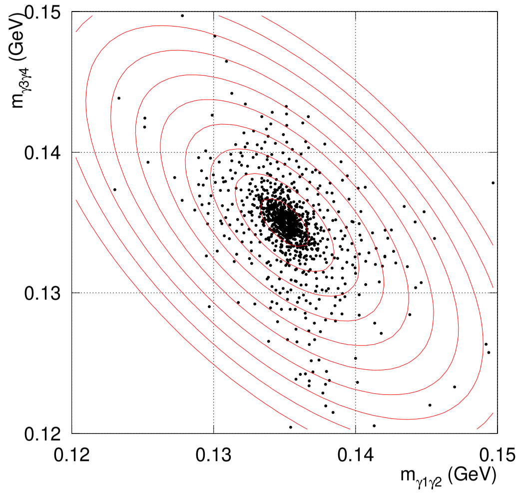
$$\frac{\sigma(E)}{E} = \frac{3.5\%}{\sqrt{E}} \oplus \frac{110MeV}{E} \oplus 0.6\%$$

Neutral Background

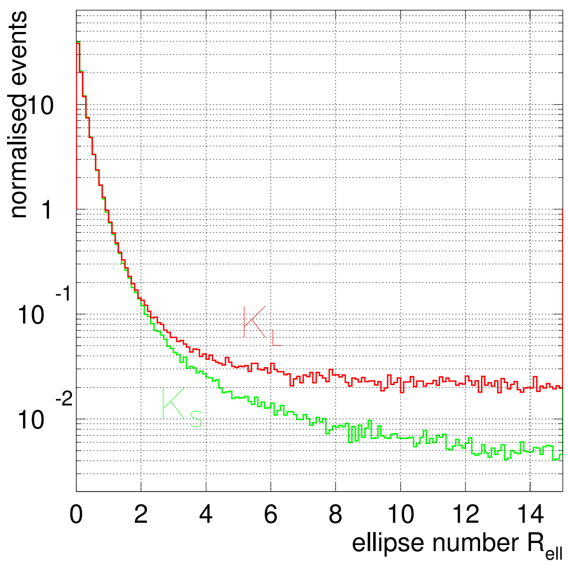
K_L



K_S



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



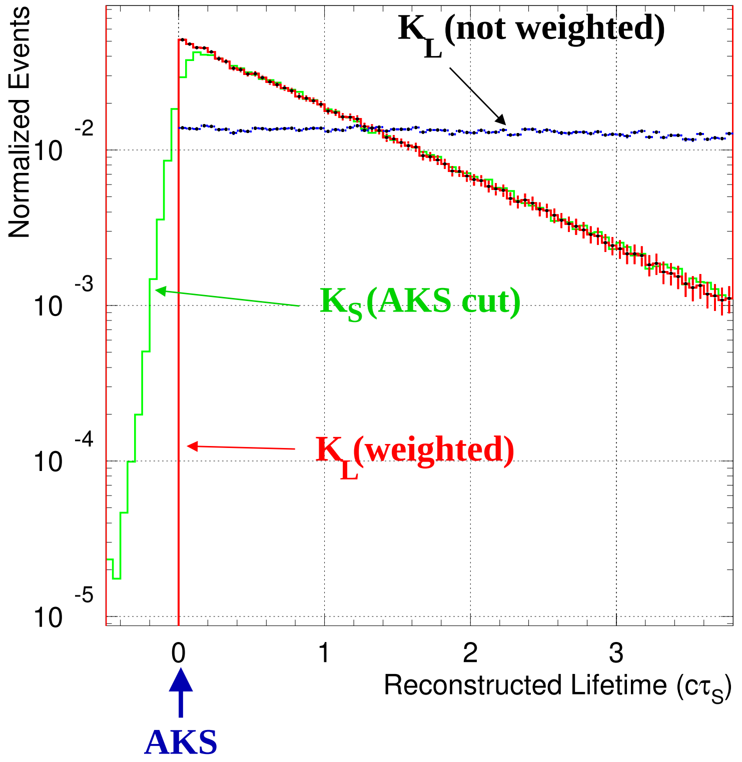
Signal region : $R_{ell} < 1.5$

Background level

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

weighted $\sim 1.10^{-3}$

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

Other sources of systematics

- Differential K_L -K_S accidental activity
  - studied by overlaying random events
- Acceptance corrections : using MC simulation
- Energy scale ...

Conclusions from '97 data

- ε'/ε analysis still in progress.
- Dominant errors are mostly of statistical nature
- 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

$\Rightarrow$ stable operation at 3 kV

- New carbon-fiber beam pipe

$\Rightarrow$ ~ 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

$\Rightarrow$ ~ 30 % trigger rate increase

Achievements

- run from mid-May untill September
- $\sim 2\ 10^6\ \mathrm{K_L} \rightarrow \pi^0\pi^0$
- 75 Tbytes of data recorded $\rightarrow$ being reprocessed

Prospects

- Result on ε'/ε with '97 data should be available soon
- Data taking for ε'/ε will continue in 1999 and 2000 ($\sim$ 120 days/year) to achieve a precision of 2×10^{-4}