Towards results on CP violation in kaon decays from NA48

Augusto Ceccucci
CERN

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

This talk

- Introduction
  - the NA48 method
  - K_L K_S beams
  - Detector
- The 1997 run
  - Accumulated statistics
  - detector performance
- Status of the 1997 data $\mathrm{Re}(\varepsilon'/\varepsilon)$ analysis
  - K_S tagging
  - Background subtraction
  - Lifetime weighting
- Rare decays from the 1997 run
  - $K_L \rightarrow e^+e^-\gamma$
  - $K_L \rightarrow e^+e^-\gamma\gamma$
- The 1998 run
  - Improvements with respect to 1997
  - Collected statistics
  - Preview of the 1998 data
- Prospects and conclusions

Introduction

- We are setup to measure the "direct CP violation" parameter $\mathrm{Re}(\varepsilon'/\varepsilon)$ in $K_{\mathrm{L,S}} \to \pi\pi$ decays, with an accuracy of $\sim 2 \times 10^{-4}$ using the technique of the double ratio:

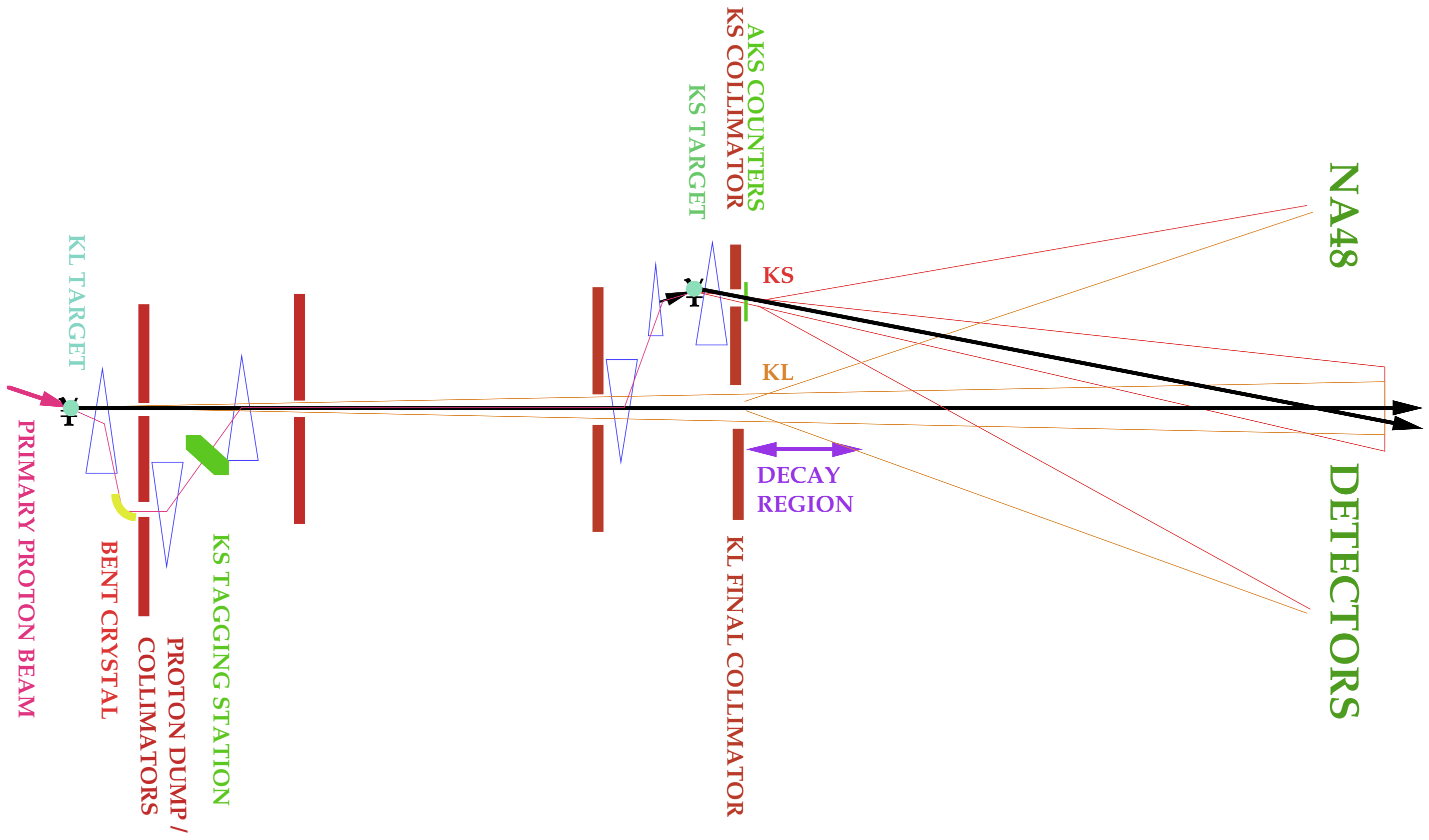
$$\mathrm{Re}(\varepsilon'/\varepsilon) \sim \frac{1}{6}\left\{1 - \frac{\Gamma(\mathrm{K_L} \to \pi^0\pi^0)}{\Gamma(\mathrm{K_S} \to \pi^0\pi^0)} \Big/ \frac{\Gamma(\mathrm{K_L} \to \pi^+\pi^-)}{\Gamma(\mathrm{K_S} \to \pi^+\pi^-)}\right\}$$

- A value of $\mathrm{Re}(\varepsilon'/\varepsilon)$ different from zero signals CP violation in a decay amplitude
- The precision measurements of $\mathrm{Re}(\varepsilon'/\varepsilon)$ available so far are:

NA31	$(2.3 \pm 0.7) \cdot 10^{-3}$
E731	$(7.4 \pm 5.9) \cdot 10^{-4}$

- NA48 collects the four decay modes concurrently, in the same detector and from the same decay region. The $\mathrm{K_S}$ is distinguished tagging the proton upstream of the $\mathrm{K_S}$ target.
- To achieve the required statistical precision we have to collect a few million $K_L \to 2\pi^0$ decays. With a $BR(\mathrm{K_L} \to \pi^0\pi^0) = (9.36 \pm 0.20) \cdot 10^{-4}$ this is the statistically limiting mode.

K_L and K_S beams (I)



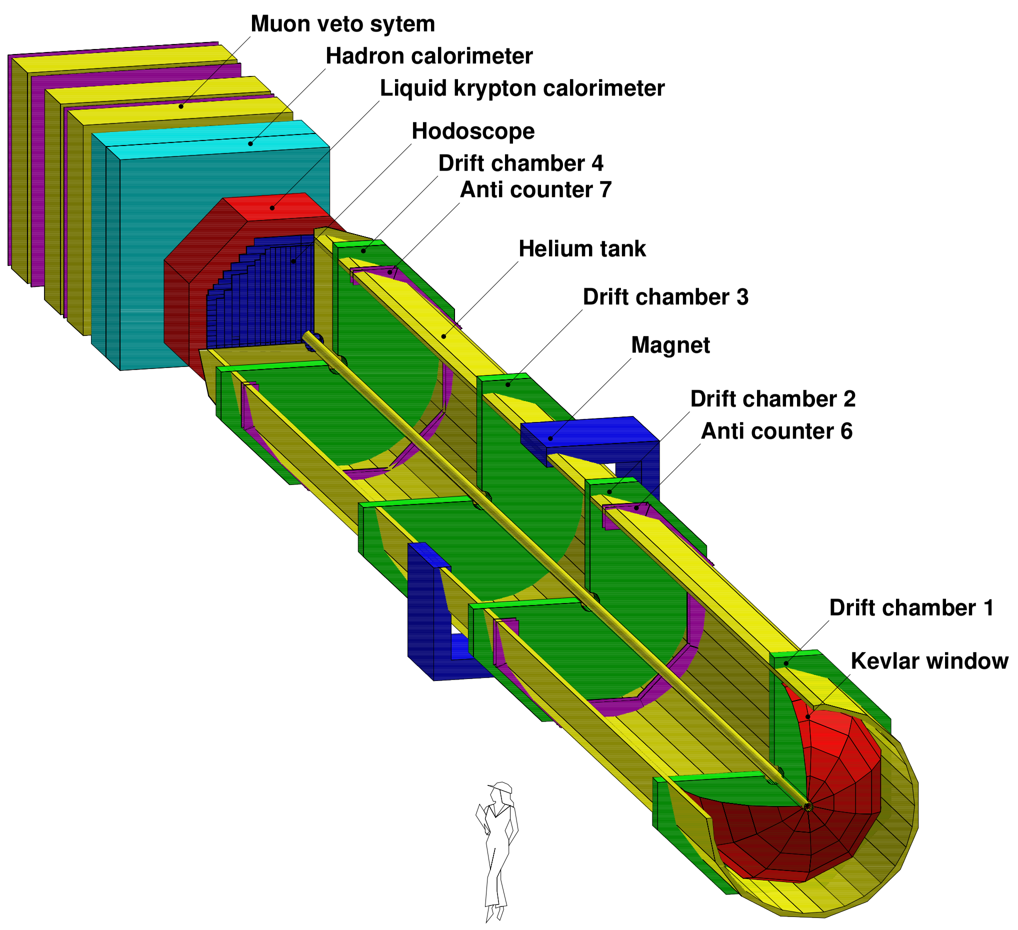
Not to scale !

K_L and K_S beams (II)

	K_L	K_S
Primary protons per pulse on target	$1.5 \cdot 10^{12}$	$3 \cdot 10^{7}$
SPS Spill length (s)/Cycle time (s)	2.38 / 14.4	
Proton Momentum, p_0 (GeV/c)	450	450
Production angle of K^0 beam (mrad.)	2.4	4.2
Length of K^0 beam: target to final collimator/AKS (m) target to front of e.m. calorimeter (m)	 126.00 241.10	 6.07 121.10
Angle of convergence of beam (mrad.)	0.0	-0.6
Angular acceptance of beam (mrad.)	$\pm$ 0.15	$\pm$ 0.375
R.M.S. radius at e.m. calorimeter (mm)	~ 26	~ 39
Useful momentum range, p_K	$70 < p_K < 170$	
Fiducial length for decays, $z=4\lambda_S$ (m)	$\sim 15 < z <\sim 36$	
K^0 flux per pulse at exit final coll.	$\sim 2 \cdot 10^{7}$	$\approx 2 \cdot 10^{2}$
decays between collimators and detector	$\sim 1.4 \cdot 10^{6}$	$\approx 2 \cdot 10^{2}$
K^0 flux per pulse in useful p_K range	$6.4 \cdot 10^{6}$	$1.5 \cdot 10^{2}$
decay per pulse in p_K range and fiducial length	$4.4 \cdot 10^{4}$	$1.5 \cdot 10^{2}$
decay per pulse to $\pi^0\pi^0$ in p_K range and fiducial length	40	45
Detector acceptance for $\pi^0\pi^0$ decays	~ 0.20	
Useful $K^0 \to \pi^0\pi^0$ per pulse	~ 8	~ 9

Rate in detector for $1.5 \cdot 10^{12}$ ppp on target	
muon flux Energy > 2 GeV in e.m. calorimeter Coinc. in opposite hodoscope quadrants	$3.9 \cdot 10^{5}$ Hz $2.9 \cdot 10^{5}$ Hz $9.7 \cdot 10^{5}$ Hz

Detector



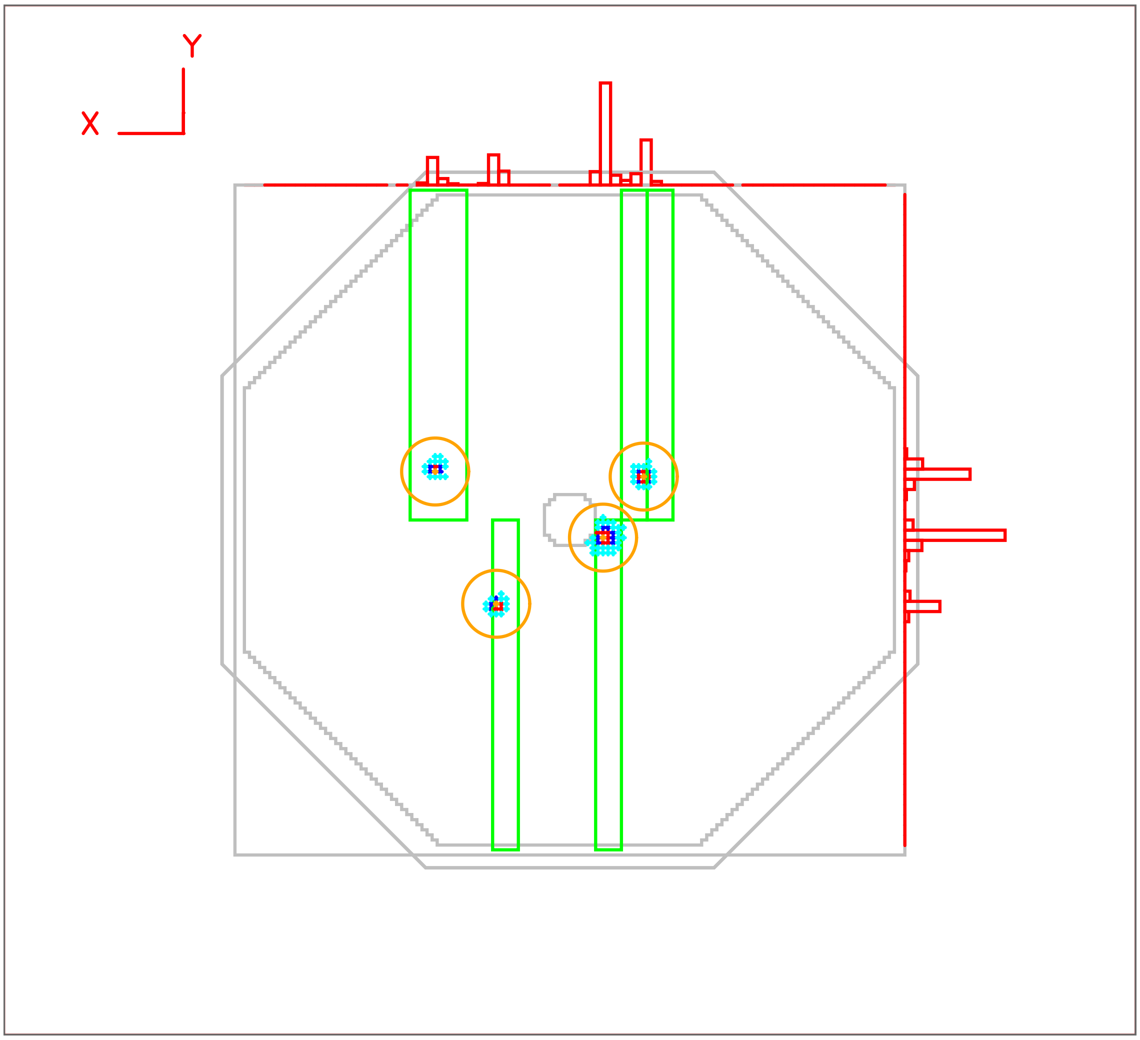
charged decays are reconstructed by a magnetic spectrometer

neutral decays are reconstructed by a quasi-homogeneous Liquid Krypton e.m. calorimeter segmented into 13212 $2 \times 2\text{cm}^2$ cells. The geometry of the calorimeter points to the centre of the K_L K_S decay region $\sim$ 114 m upstream.

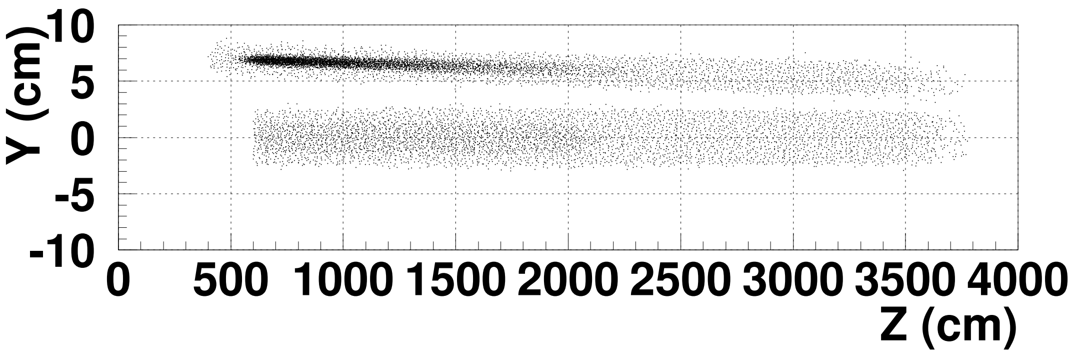
The 1997 run

First physics run Sep/Oct 1997, 42 days of $\mathrm{Re}(\varepsilon'/\varepsilon)$ data taking

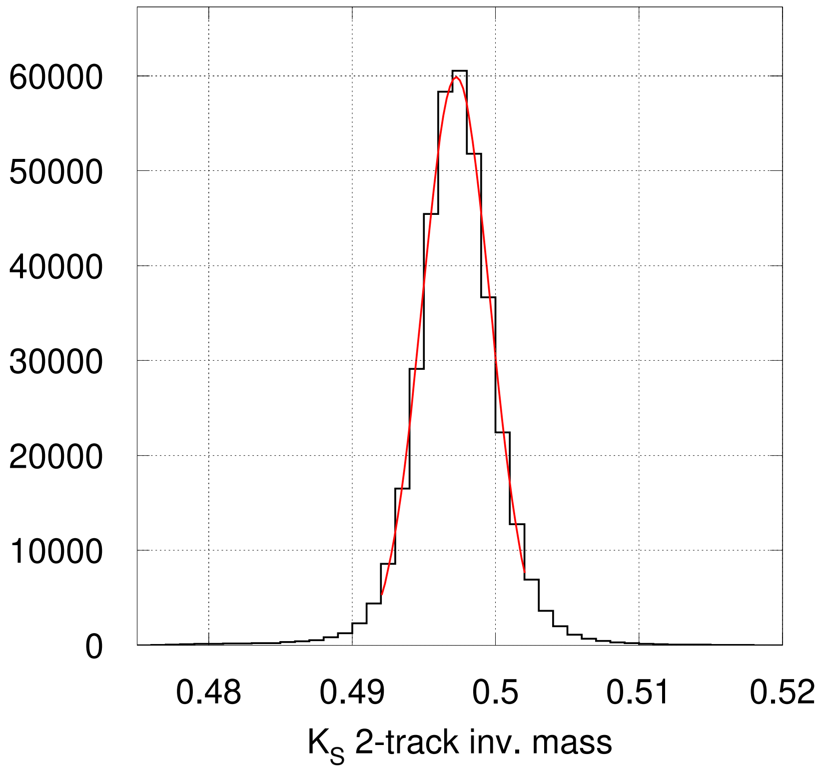
- energy: $70\mathrm{GeV} < E_{\mathrm{K}} < 170\mathrm{GeV}$
- lifetime: $0 < \tau < 4 \cdot \tau_{\mathrm{S}}$
- 650.000 $\mathrm{K_L} \rightarrow \pi^0\pi^0$



1997 run: charged detector performance

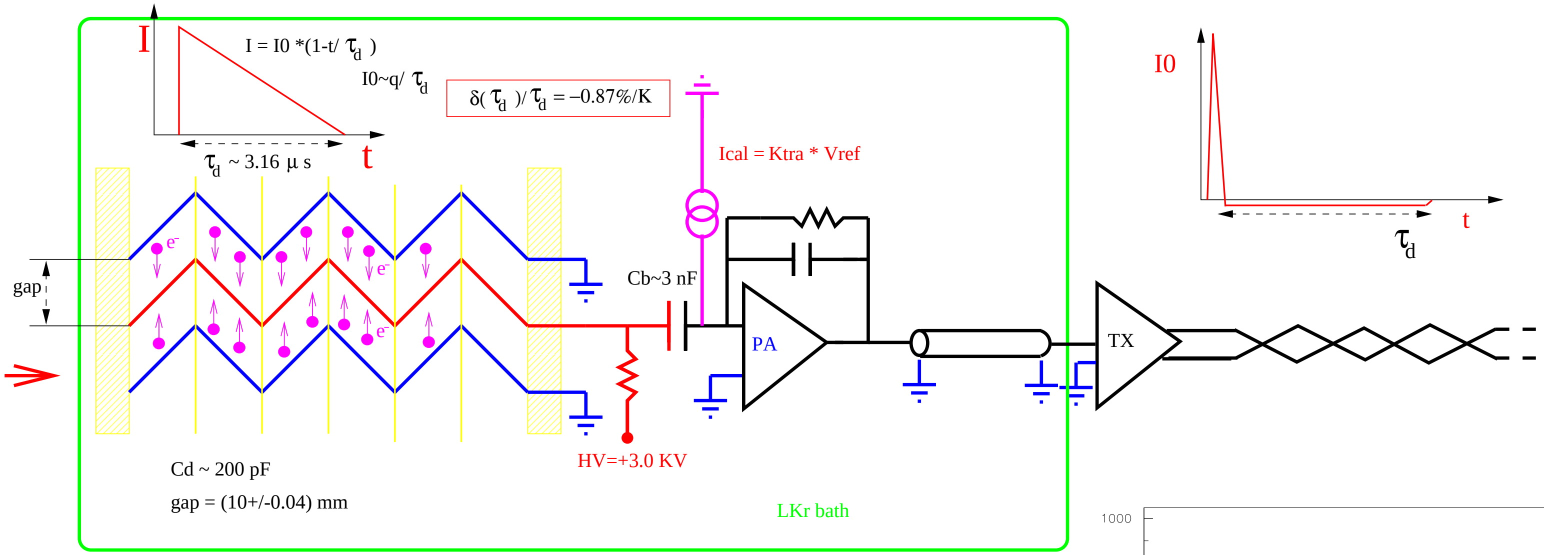


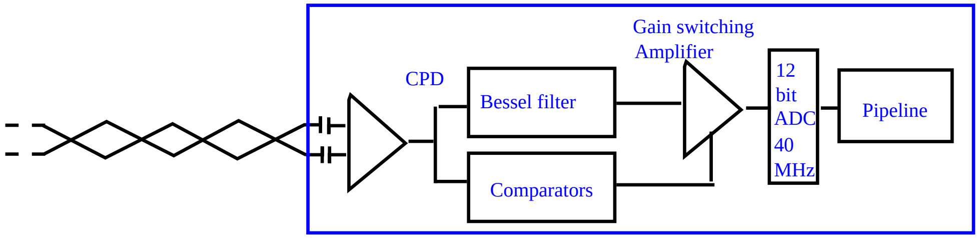
The beginning of the decay region for the K_S beam (above in the figure) is determined asking for no hits in the AKS counter placed on the beam. For the K_L beam instead a cut $\tau = 0$ on the reconstructed proper time is applied.

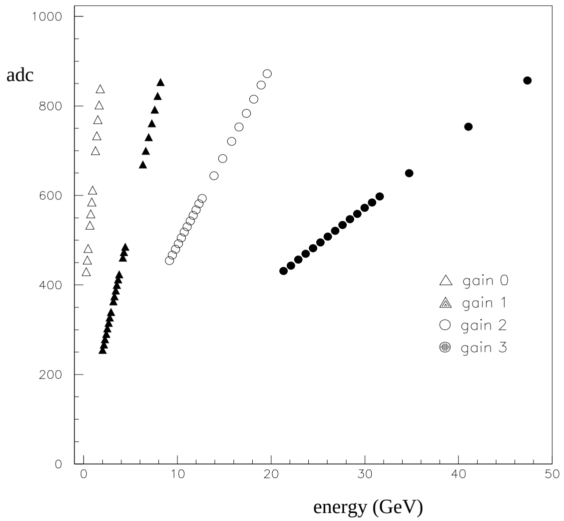


The invariant mass resolution for K is 2.5 MeV/c^2

Calibration of the LKr calorimeter

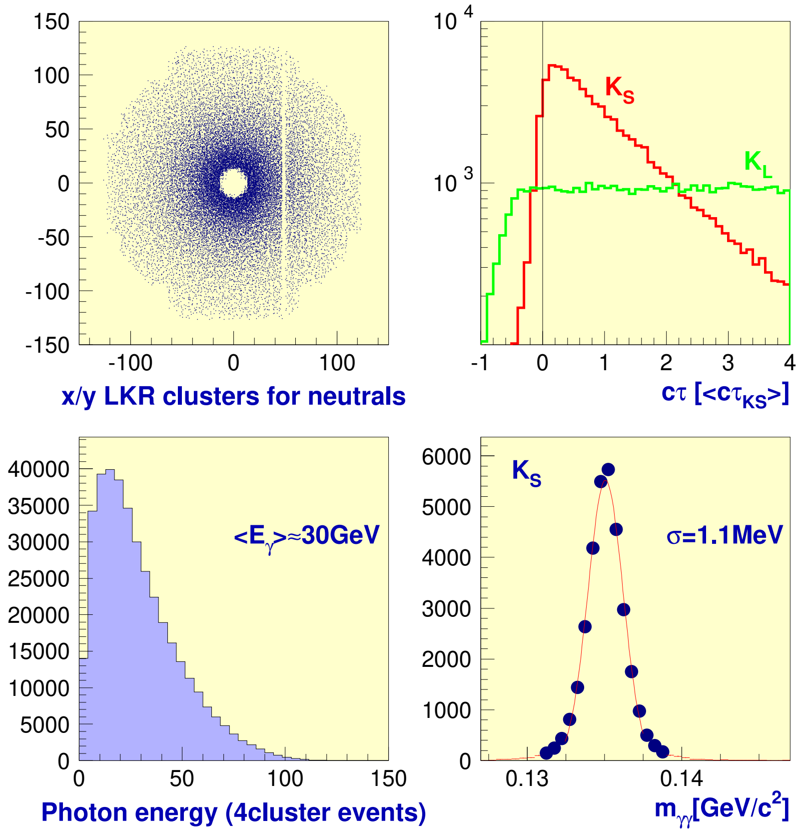






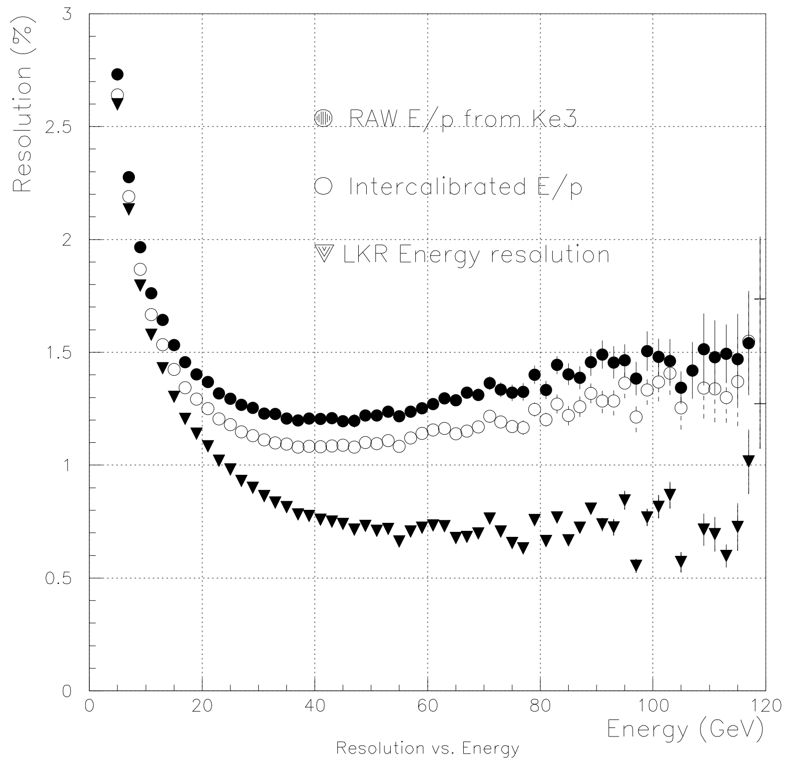
(4 offsets + 4 slopes) * 13212 channels = 105696 constants

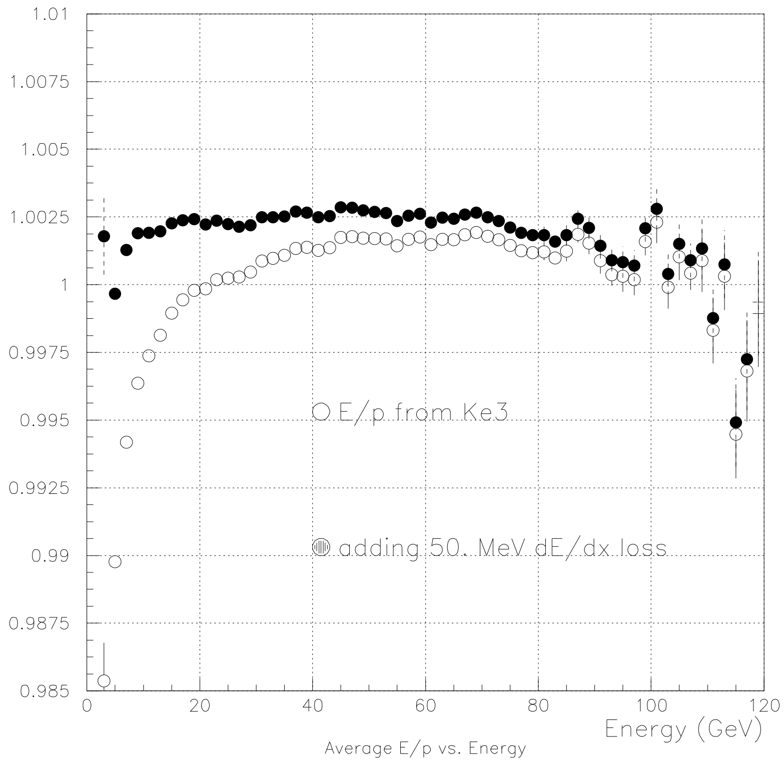
1997 run: LKr Performance



- LKr calorimeter operated at reduced bias (1.5 KV) because of failure of a few blocking capacitors
- one LKr column (four cm wide) not connected to high voltage

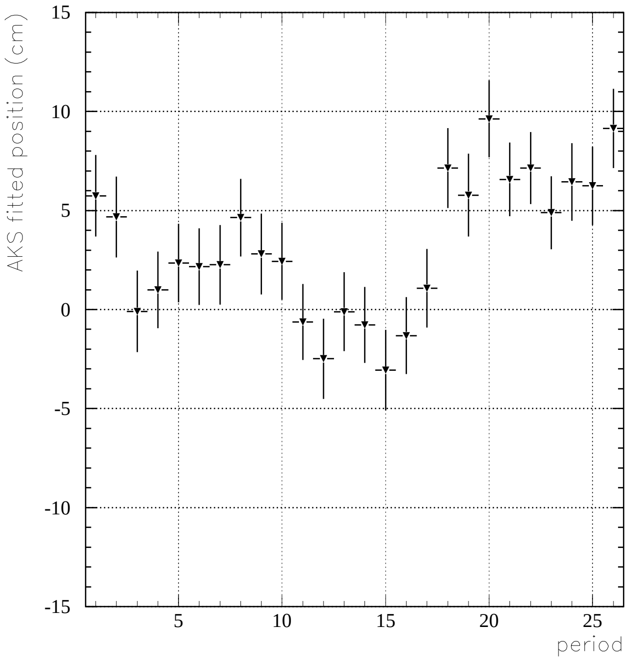
1997 run: LKr resolution and linearity





The reduced HV implied a $\sim 20\%$ increase in the electronics noise (total noise=130 MeV/shower) and a small ($< 0.5\%$) space charge correction to the energy measurement.

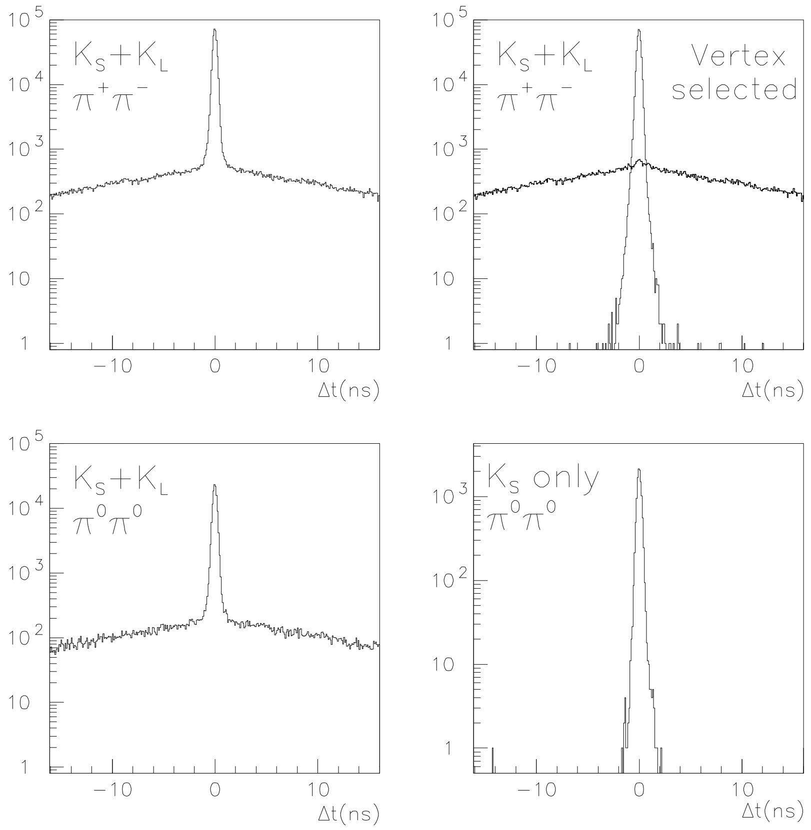
run 1997: LKr stability



- The gain of the electronics is checked regularly
- To (slightly) improve the resolution one *localized* (i.e. averaged with the neighbours) factor for each cell is allowed.
- These factors are static factors, not function of the time
- The absolute calibration is obtained fitting the steep rise of the vertex distribution for the K_S events requiring no hits in the AKS counter and adjusting the fitted value to the known position of the counter.

The peak-to-peak variation of the AKS fit is $\pm 6.5cm$ corresponding to a peak-to-peak momentum error of $\pm 5 \cdot 10^{-4}$

1997 Re(ε'/ε) : proton tagging



$\pi^0\pi^0$: $\Delta t = t_{\mathrm{LKr}} - t_{\mathrm{TAG}}$
$\pi^+\pi^-$: $\Delta t = t_{\mathrm{HOD}} - t_{\mathrm{TAG}}$
t_{TAG} = time of the nearest hit in tagger

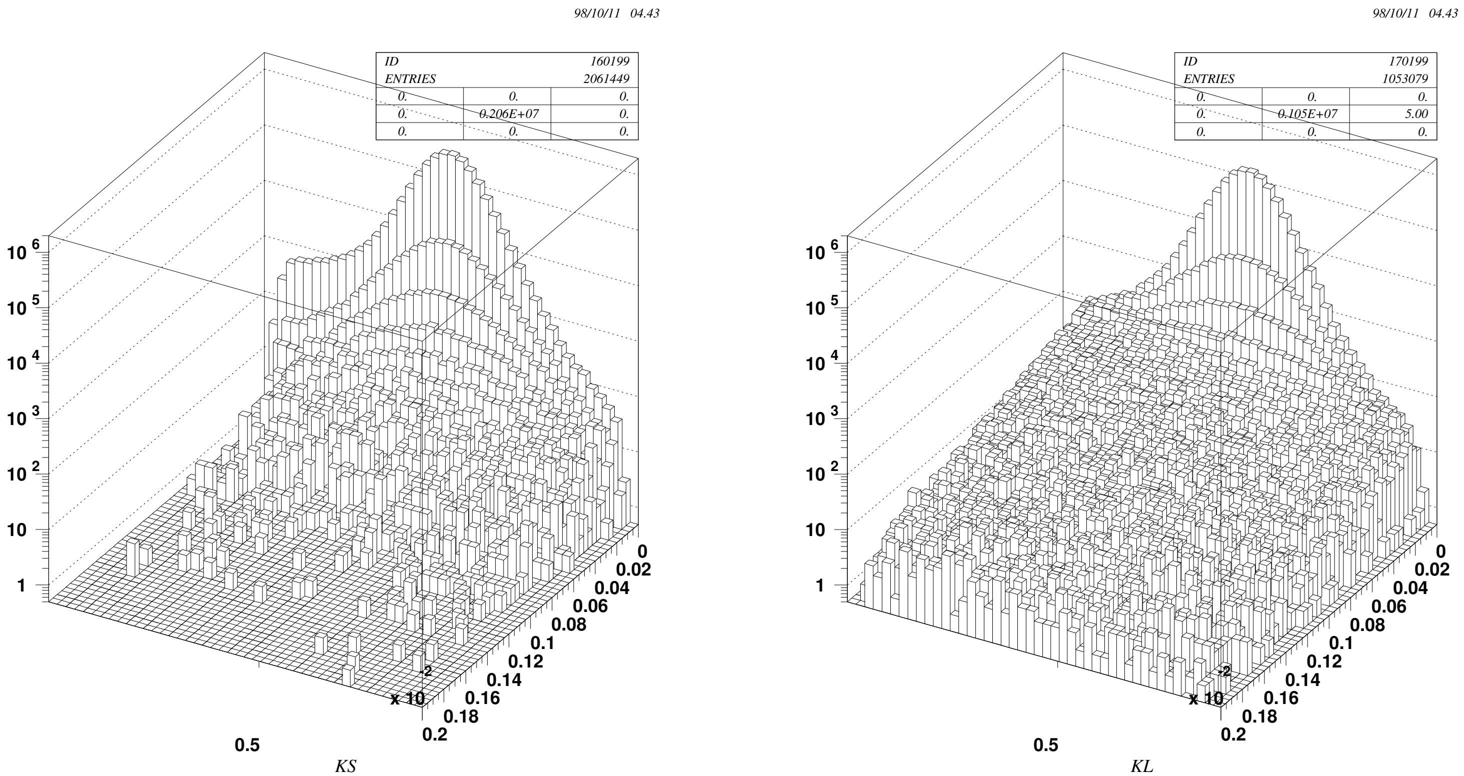
$\mathrm{K_S} \equiv |\Delta_t| \leq 2$ns

Tagging inefficiencies are a few 10^{-4}. For charged decays they are measured directly selecting the vertex of decay for the $\pi^+\pi^-$ pair. For the neutral events checks using $\mathrm{K_S} \to \pi^0 e^+ e^- \gamma$ events and $\mathrm{K_S}$ *only* runs are made.

$\mathrm{K_L} \equiv |\Delta_t| > 2$ns

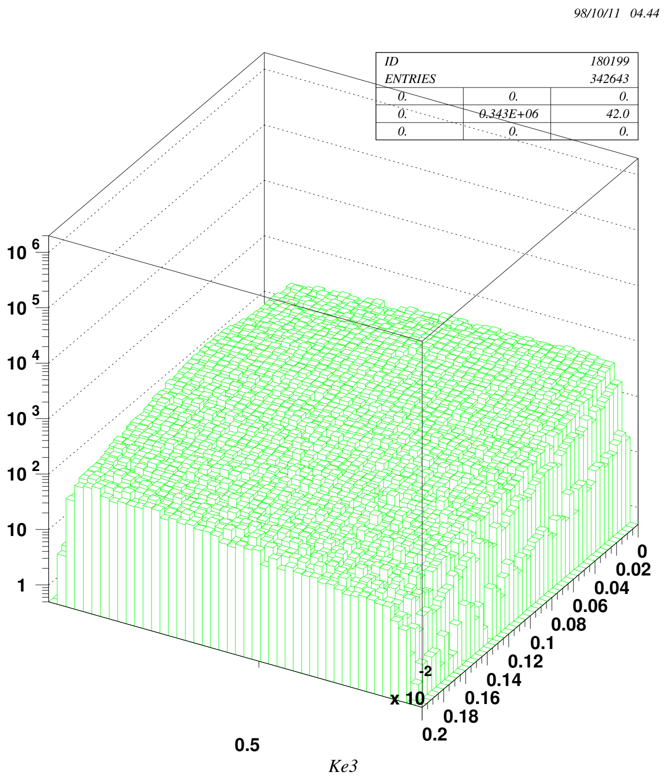
Accidental activity in the tagger causes $\mathrm{K_L} \to \mathrm{K_S}$ migration which dilutes Re(ε'/ε) . The dilution has been measured to be $(11.5 \pm 0.03)\%$

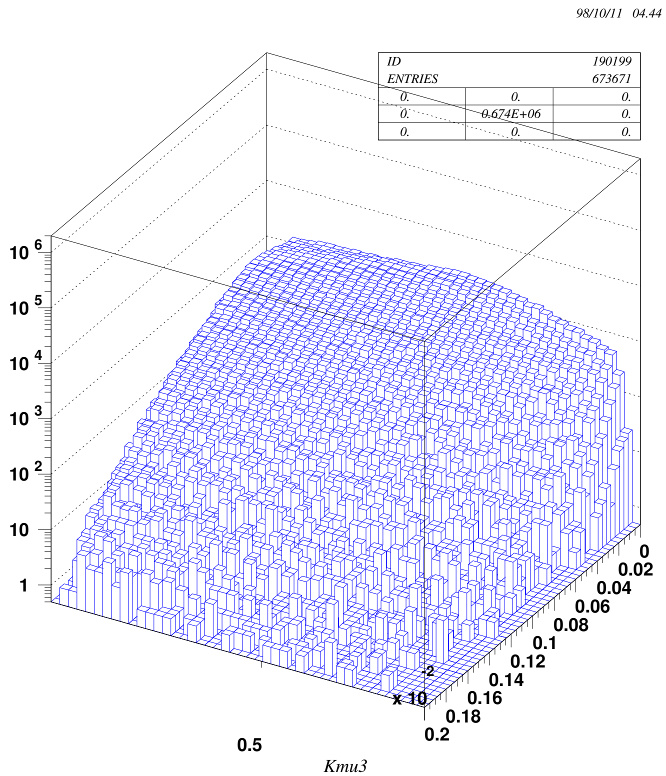
1997 Re(ε'/ε) : $K_{\mu3}$ and K_{e3} under the $\pi^+\pi^-$ (I)



$K_{\mu3}$ and K_{e3} are respectively ~ 131 and ~ 188 times more frequent than $\pi^+\pi^-$ decays. The background under the signal region has to be kept to a few per mill.

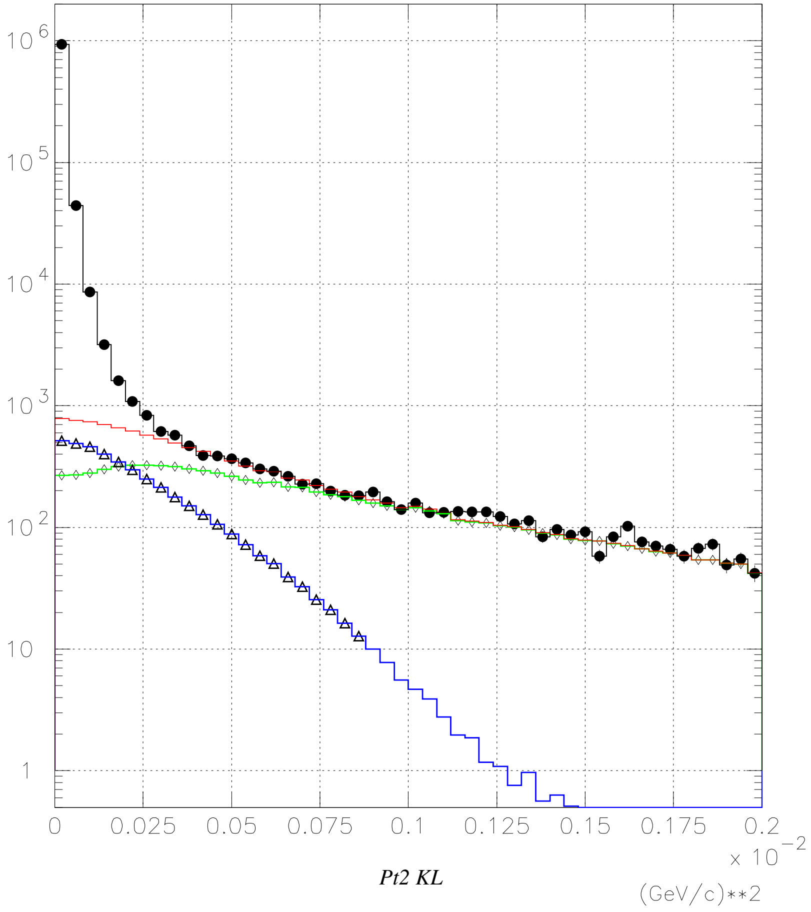
1997 $\mathrm{Re}(\varepsilon'/\varepsilon)$: $K_{\mu 3}$ and K_{e3} under the $\pi^+\pi^-$ (II)





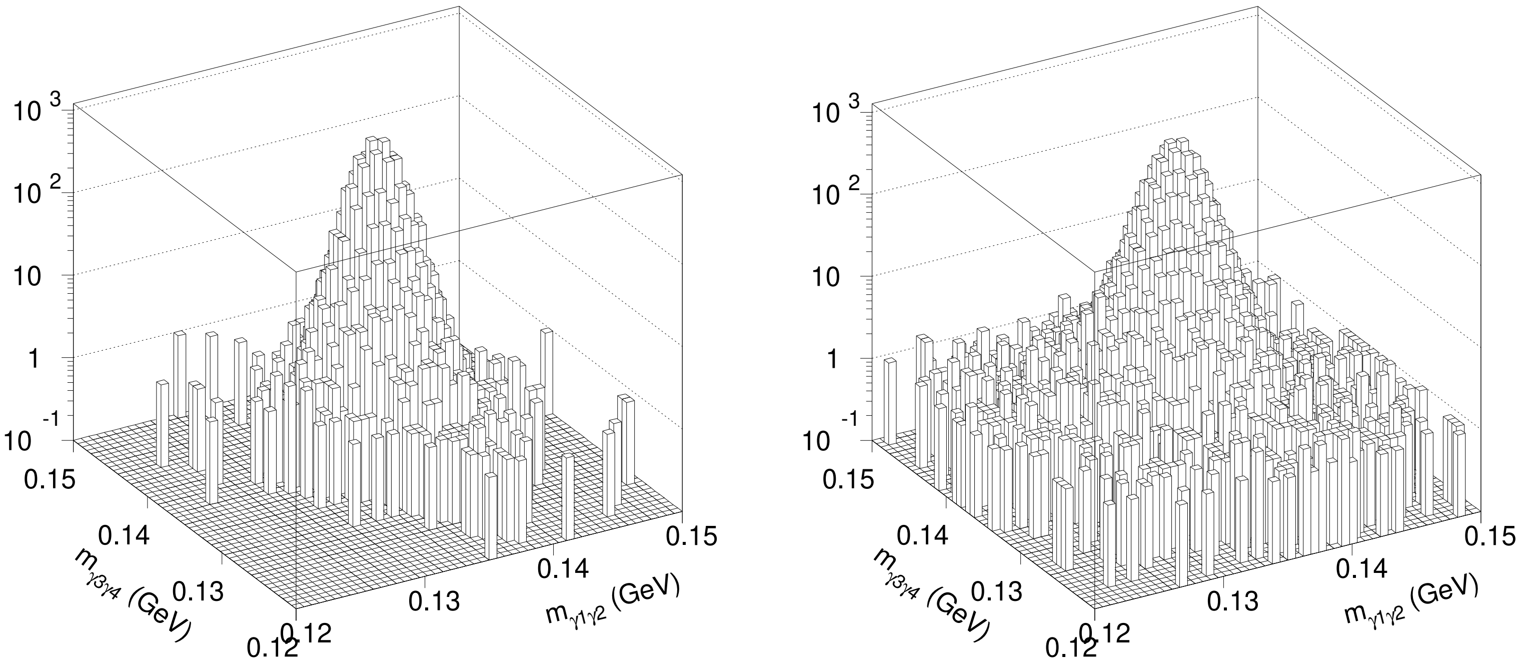
selected samples of K_S , K_{e3} and $K_{\mu 3}$ are used to fit the K_L distributions.

1997 $\mathrm{Re}(\varepsilon'/\varepsilon)$: $\mathrm{K}_{\mu3}$ and K_{e3} under the $\pi^+\pi^-$ (III)



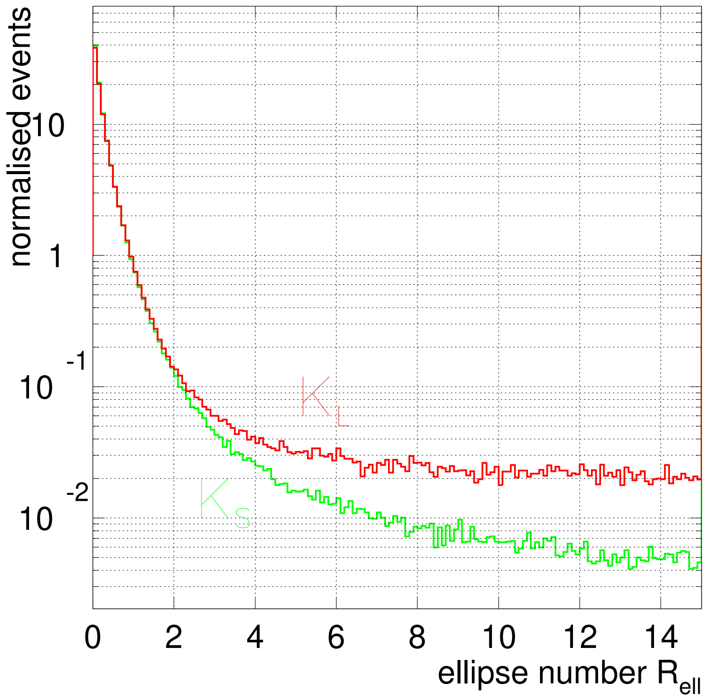
Preliminary! The background extrapolated below the $\mathrm{K_L} \to \pi^+\pi^-$ peak is $\sim 3 \cdot 10^{-3}$ with a statistical error ten times smaller. Notice that the $\mathrm{K}_{\mu3}$ component in blue has a steeper p_T^2 dependence.

1997 $\mathrm{Re}(\varepsilon'/\varepsilon)$: $3\pi^0$ under the $2\pi^0$ (I)



$K_L \rightarrow 3\pi^0$ decay mode is $\sim$ 221 times more frequent than $\pi^0\pi^0$ and can mimic it if two photons are missed. The kaon mass is used as constraint to calculate the neutral decay vertex. Photons are then paired in order to form the best $\pi^0\pi^0$ combination. Events with five photons are allowed only if $\Delta t = |t_{\pi^0\pi^0} - t_{5th}| < 3$ ns.

1997 Re(ε'/ε) : $3\pi^0$ under the $2\pi^0$ (II)

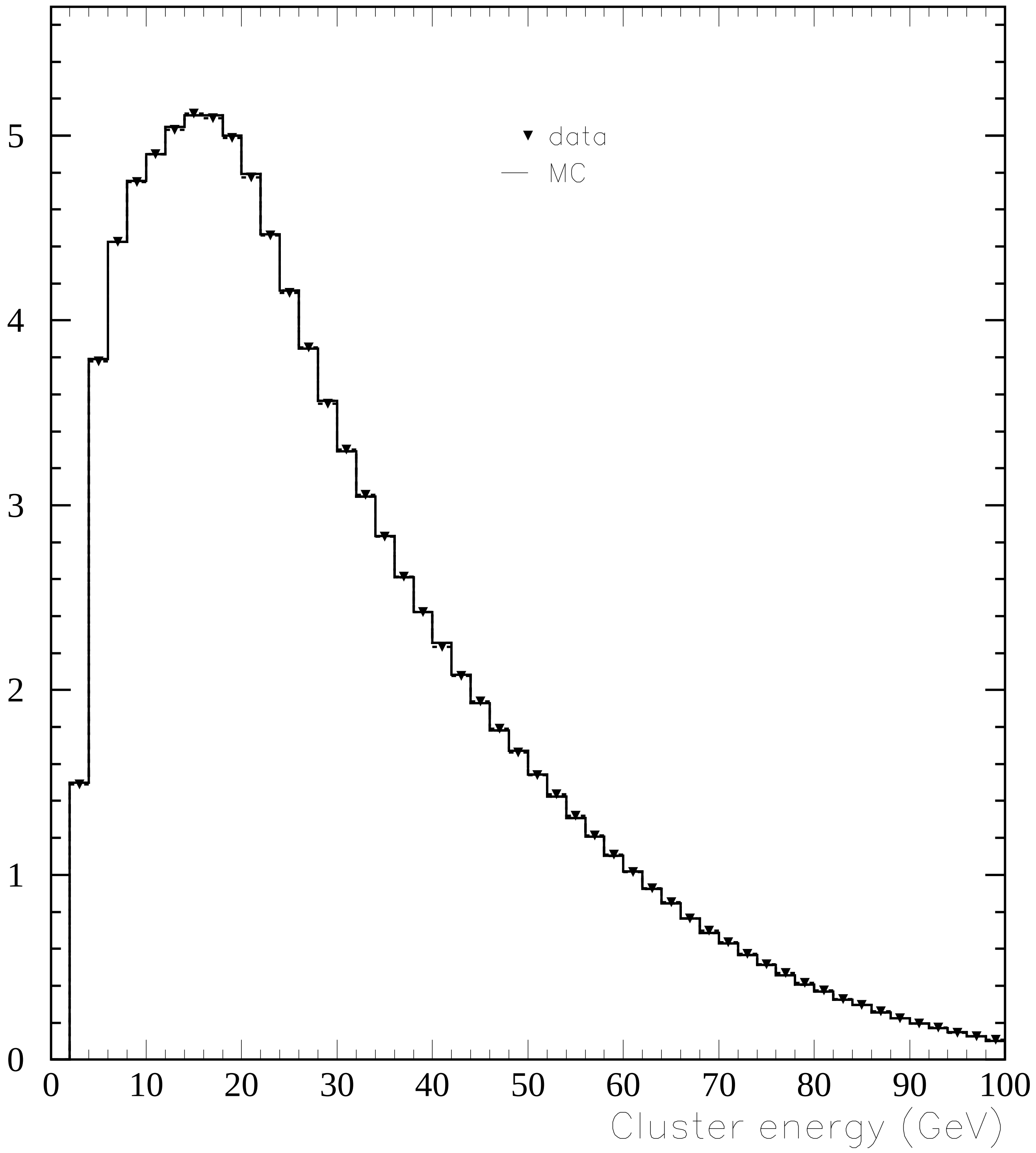


In this example, the signal region is defined as $R_{ell} < 1.5$

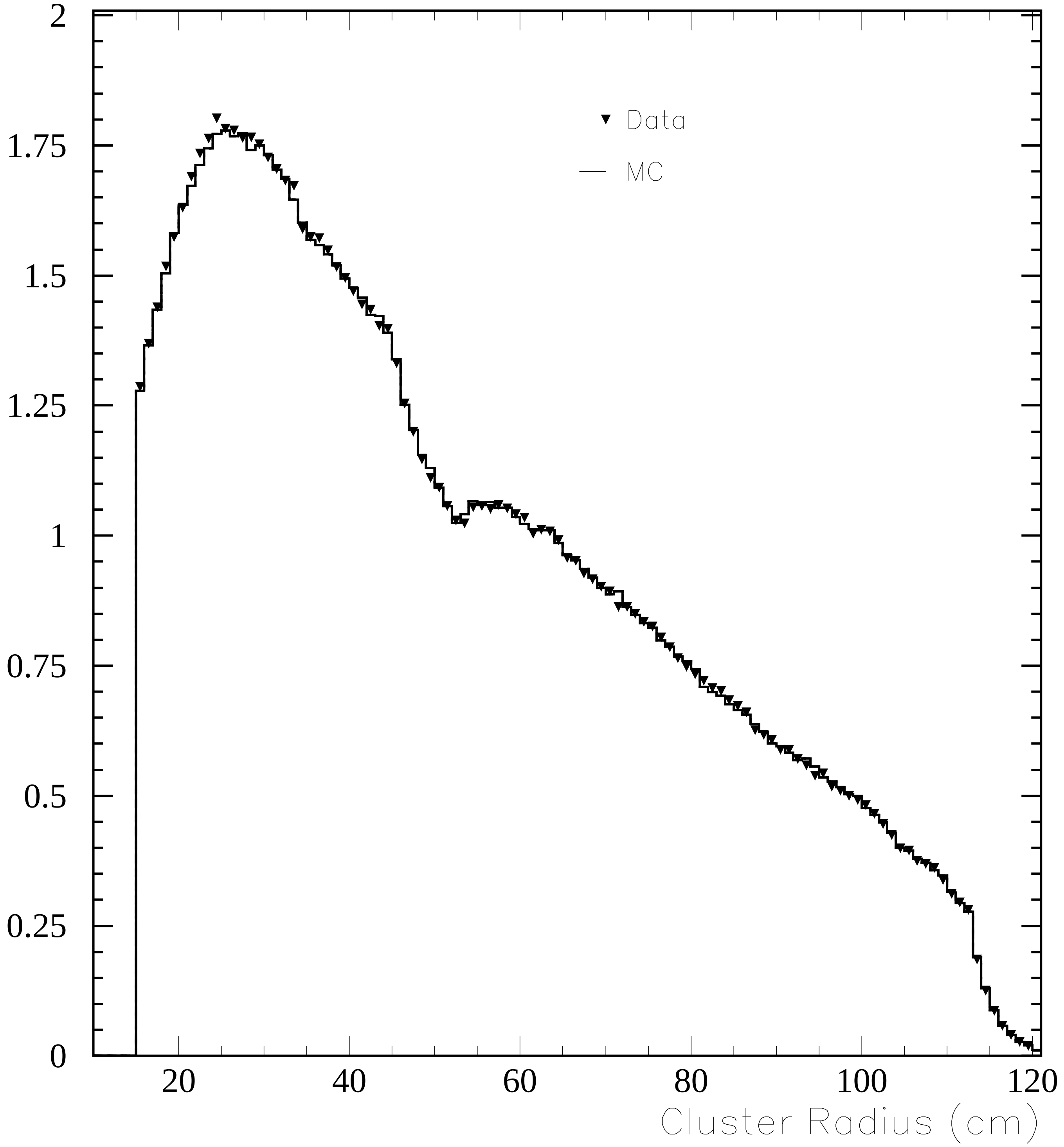
$$R_{ell} \equiv \frac{1}{9}\left\{\left(\frac{\frac{m_1+m_2}{2} - m_{\pi^0}}{\sigma_{\frac{m_1+m2}{2}}}\right)^2 + \left(\frac{\frac{m_1-m_2}{2}}{\sigma_{\frac{m_1-m2}{2}}}\right)^2\right\}$$

The background is $\sim 3 \cdot 10^{-3}$ if no lifetime weighting is applied. Applying weighting the background drops to $\sim 1 \cdot 10^{-3}$. This is because $3\pi^0$ decays with missing photons tend to be reconstructed closer to the calorimeter.

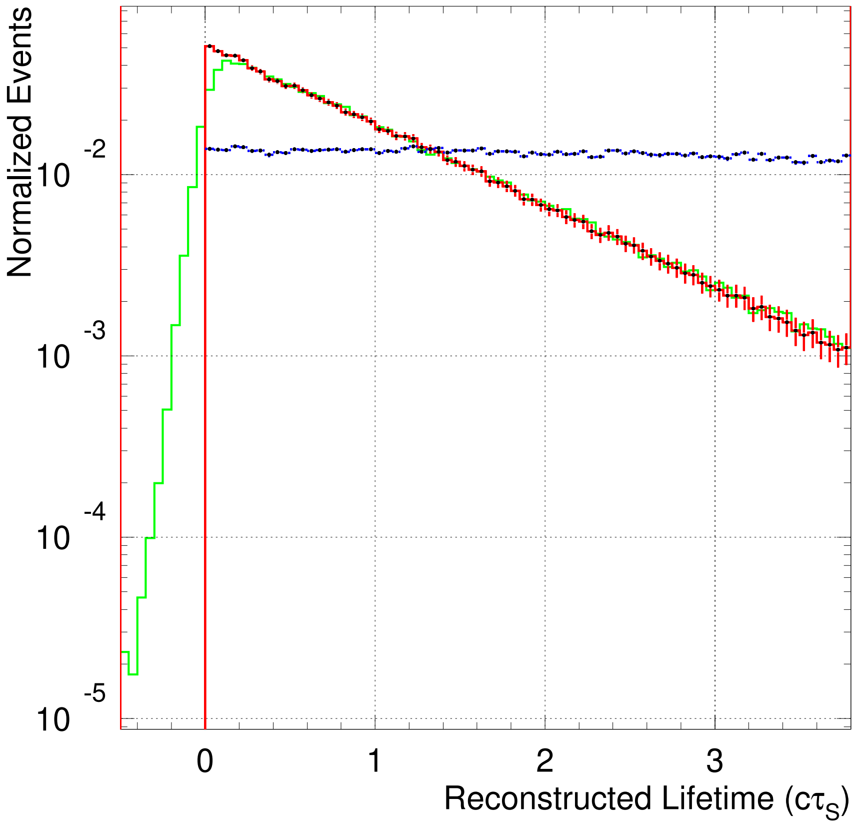
1997 Re(ε'/ε) : Data vs simulation (I)



1997 Re(ε'/ε) : Data vs simulation (II)



1997 Re(ε'/ε) : lifetime weighting



To make the decay vertex distribution similar, one plans to weight down the K_L events by a factor:

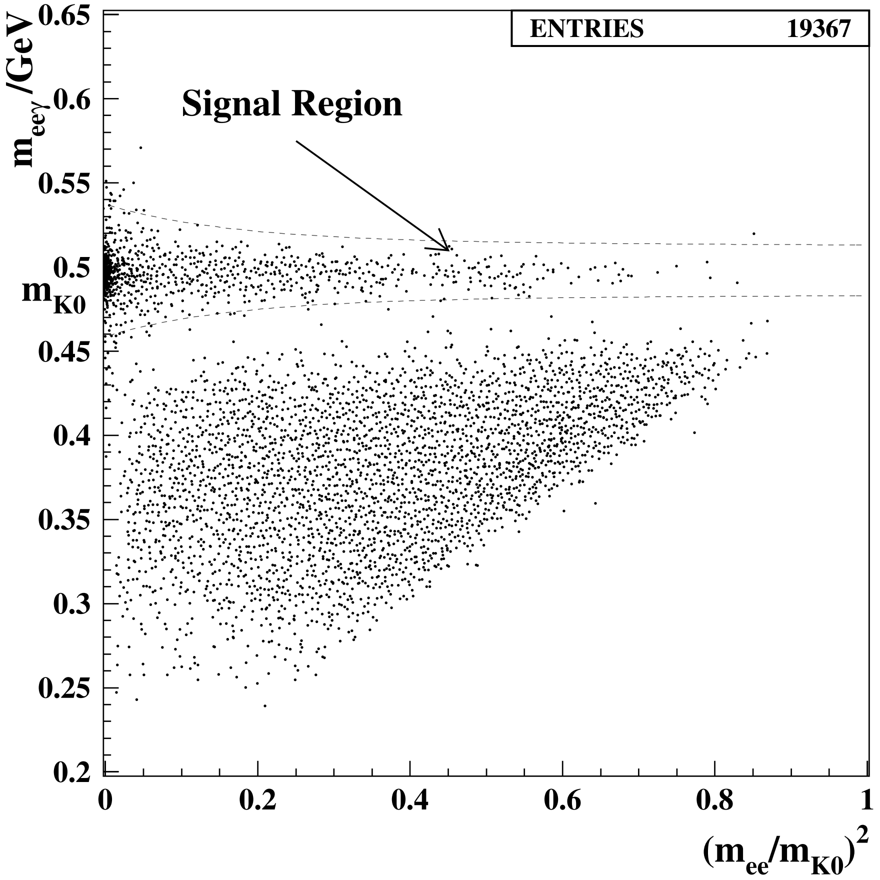
$$\exp\left(-\frac{(z_{\mathrm{REC}} - z_{AKS})m_{\mathrm{K}}}{c\tau_{\mathrm{S}}E_K(1-\tau_{\mathrm{S}}/\tau_{\mathrm{L}})}\right)$$

Applying this technique the acceptance correction is substantially reduced. The price is an increase of the statistical error by 15% for a decay region of $2\tau_{\mathrm{S}}$.

1997 $\mathrm{Re}(\varepsilon'/\varepsilon)$ Conclusions

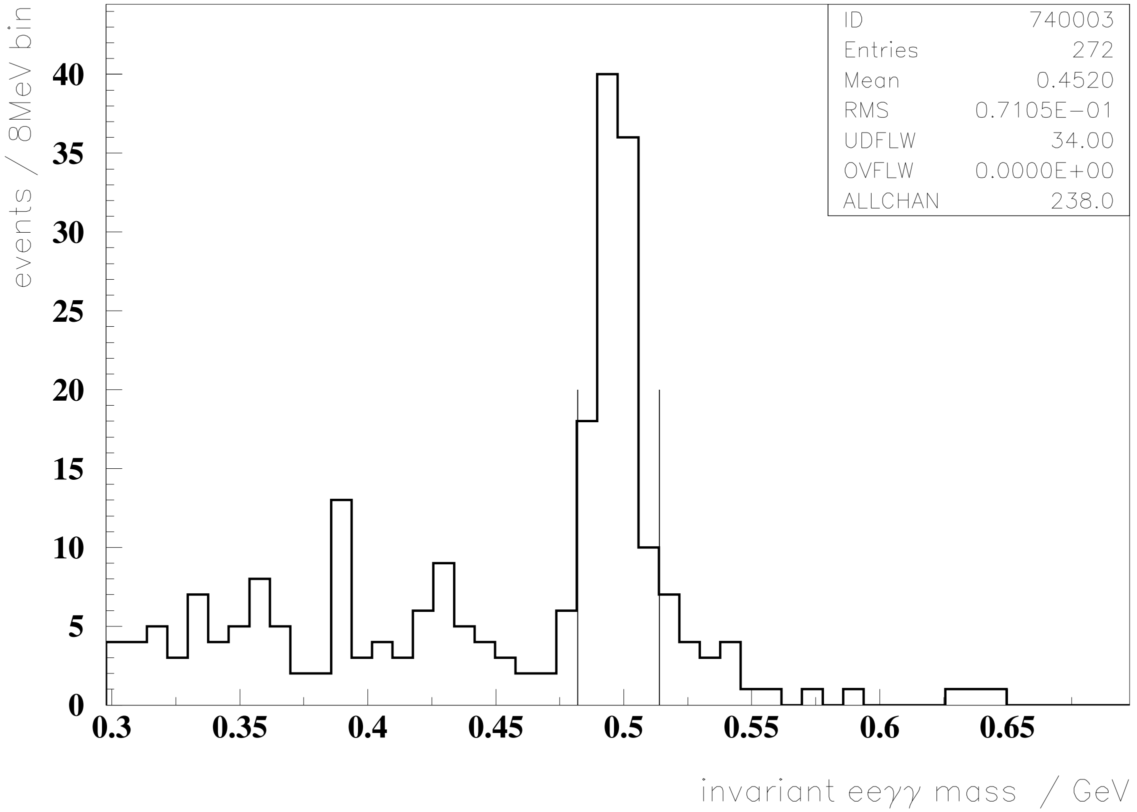
- We are close to a result based on the 1997 sample: it should be available by the winter conferences.
- The statistical error will be $4 \div 5 \cdot 10^{-4}$
- The systematic error should be smaller than the statistical one

1997 data: $K_L \rightarrow e^+e^-\gamma$



- Expect a precise measurement of the BR and of the parameter α_{K^*} for the $K\gamma\gamma^*$ form factor
- The signal is very well separated from the background
- 6786 events lie in the signal region
- Main background from $K_L \rightarrow \pi^0\pi^0{}_D$
- The background is 9.7 ± 1.3 events in total

1997 run: $K_L \rightarrow e^+e^-\gamma\gamma$



Preliminary: $BR(K_L \rightarrow e^+e^-\gamma\gamma) = (4.6 \pm 0.7 \pm 1.4) \cdot 10^{-7}$

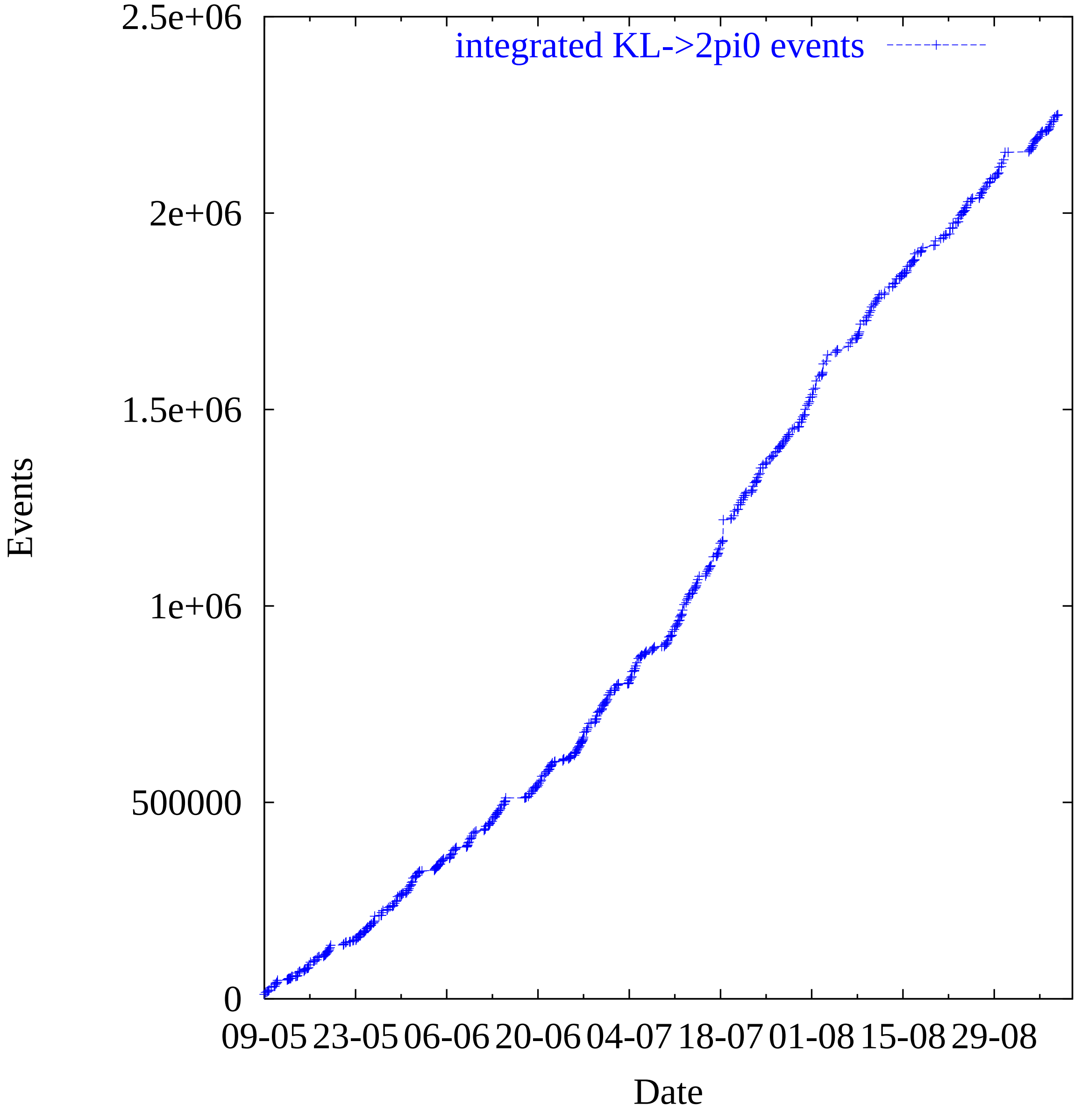
Conditions: $E_\gamma > 5$ MeV and $m_{e\gamma} > 1$ MeV

The 1998 run

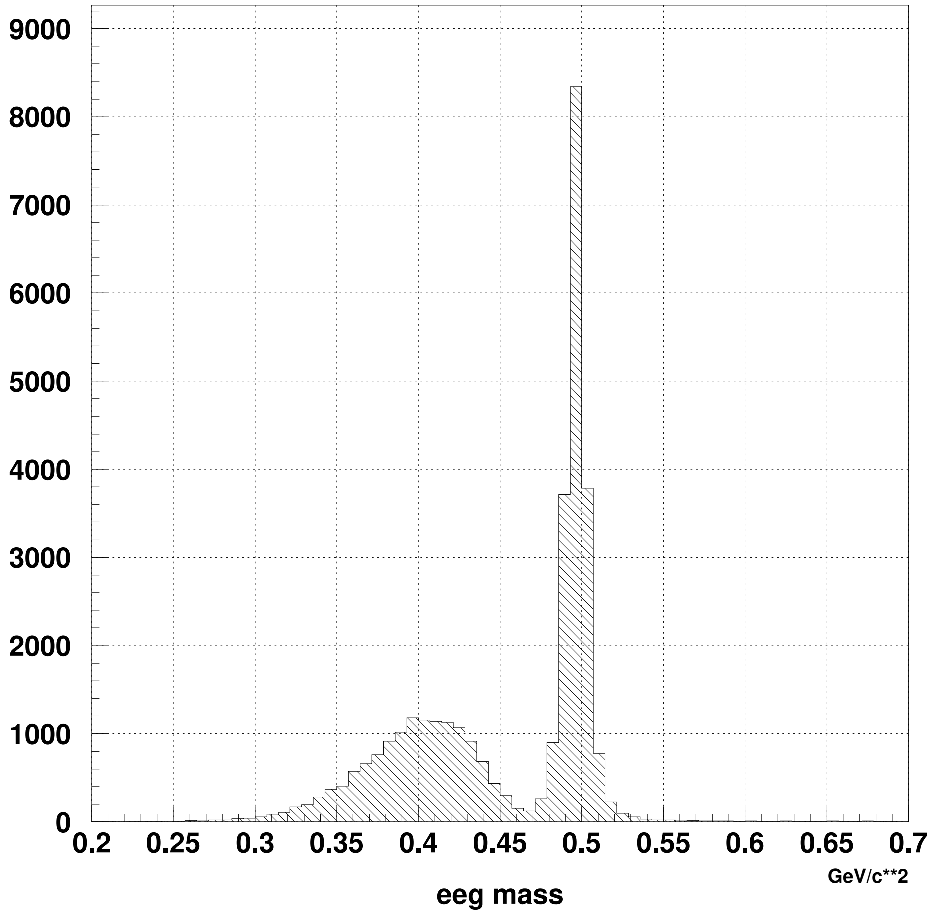
- From May until September: $\sim$ 110days of Re(ε'/ε) data taking Blocking capacitors of the Calorimeter replaced $\rightarrow$ HV=3.0 KV ; $\sigma_{m_{\pi^0}} \leq 1MeV/c^2$
- New charged trigger processors: $\rightarrow$ less dead time and no Level I down-scaling needed for the $\pi^+\pi^-$ trigger
- Stainless steel beam-pipe replaced by a light C-fibre one: $\rightarrow$ reduction of dead time for the DCH read-out (less showers from K_L decays in chambers).
- New event building PC farm commissioned $\rightarrow\sim 18Mb/s$ DC transfer rate; Increase of sustained trigger rate by $\sim$ 30%.

1998 run: accumulated statistics

- energy: $70\text{GeV} < E_{\text{K}} < 170\text{GeV}$
- lifetime: $0 < \tau < 3.5 \cdot \tau_{\text{S}}$

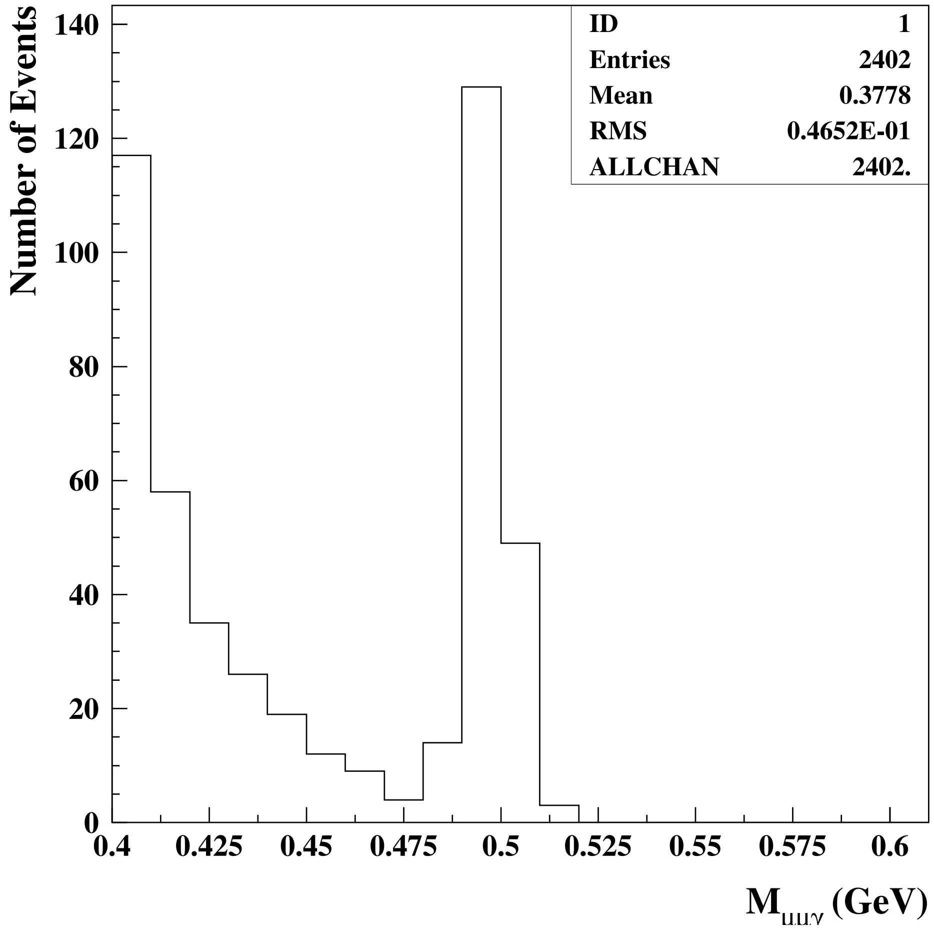


1998 preview: $K_L \to e^+e^-\gamma$



- 1998 data: preliminary!
- $\sim \frac{2}{3}$ of statistics
- from real time reconstruction histograms

1998 run: $K_L \rightarrow \mu^+\mu^-\gamma$



- $\frac{1}{13}$ of statistics
- expect more than 2000 events from the entire 1998 statistics

Conclusions

- A result based on the 1997 statistics should be available soon
- We are re-processing the 75 Tb of data collected during the 1998 run
- There will be $\sim$ 110 days of $\mathrm{Re}(\varepsilon'/\varepsilon)$ data taking during the 1999 SPS proton run