Status of the NA48 experiment on direct CP violation in Kaon decays

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NA48 COLLABORATION

Cagliari-Cambridge-CERN-Dubna-Edinburgh-Ferrara-Firenze-Mainz-Orsay-
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Outline

- The NA48 experiment
  - Aim and Method
  - History
  - The K_L and K_S Beams
  - Detectors
  - Triggers
- The 97 data analysis
  - Statistics
  - $\mathrm{K_S}$ Tagging
  - Backgrounds
  - Lifetime weighting
  - Energy scale
  - Status
- The 1998 Data
  - Improvements
  - Statistics
  - Status
- Preparation of the 1999 run
  - Main changes
  - Prospects
- Future Plans
  - Year 2000
  - Beyond year 2000
- Conclusions

Aim and Method

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

Previous precision measurements :

NA31	$(23 \pm 6.5) \cdot 10^{-4}$
E731	$(7.4 \pm 5.9) \cdot 10^{-4}$
KTEV (prelim.)	$(28.0 \pm 4.1) \cdot 10^{-4}$

Double ratio technique :

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

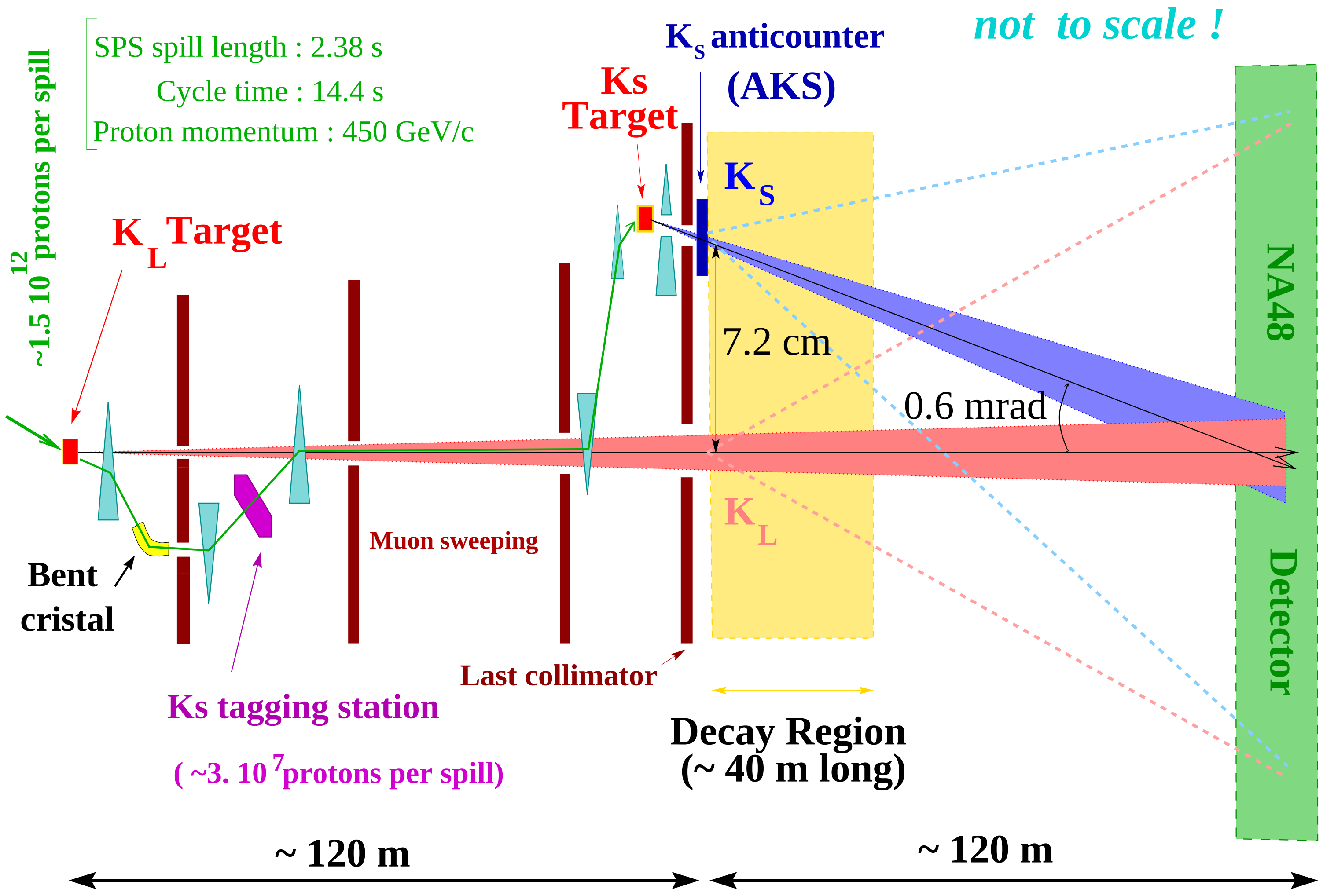
- Collect $4 - 5\ 10^6$ $\mathrm{K_L} \to \pi^0\pi^0$ (limiting mode)
- Minimize corrections → the 4 modes are measured
  - Simultaneously
  - From the same fiducial volume : Use lifetime weighting of Kl to make identical Z vertex distributions for Kl and Ks
  - With a magnetic spectrometer for the $\pi^+\pi^-$ mode
  - With a Liquid Krypton homogeneous calorimeter for the $\pi^0\pi^0$ mode

⇒ achieve good resolutions and small background levels

History

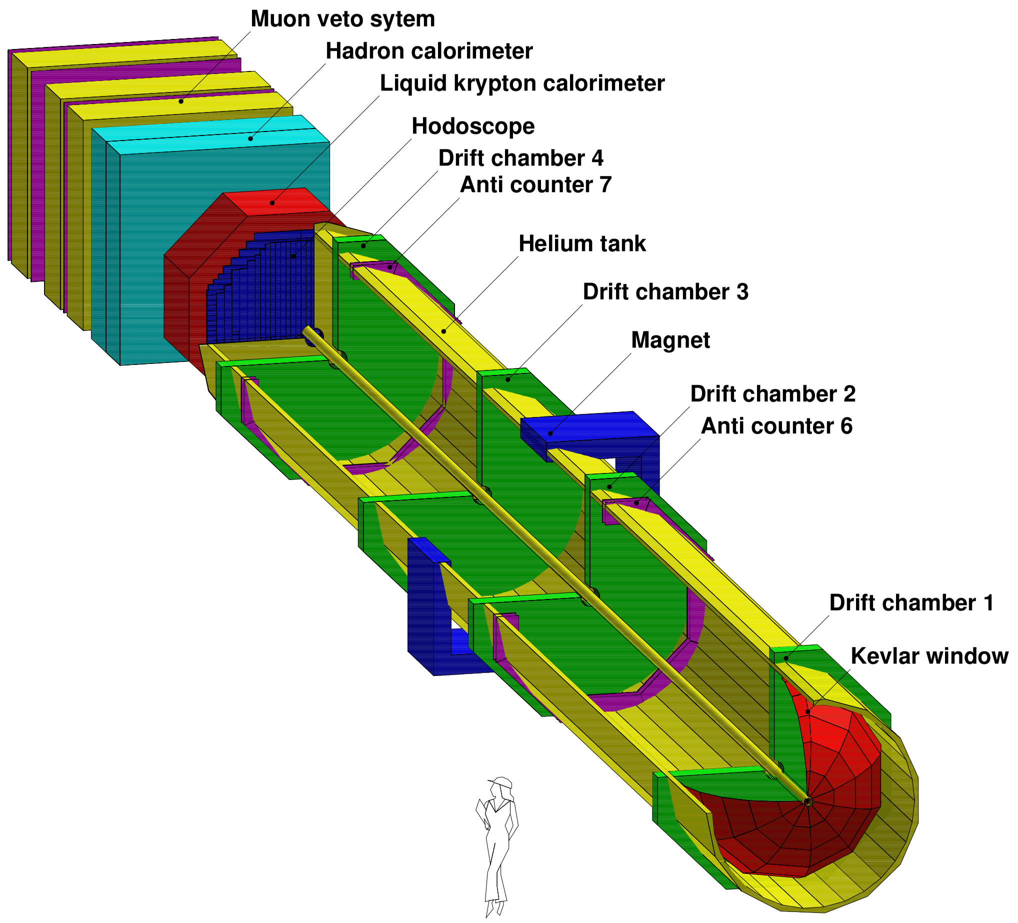
1990	:	Proposal
1991-94	:	Beams and detectors installation Tests of LKr calorimeter prototypes
1995	:	Commissioning of the Magnetic Spectrometer
1996	:	Commissioning of the Liquid Krypton Calorimeter
1997	:	First Re(ε'/ε) Data Taking (42 days)
1998	:	Continue Re(ε'/ε) Data Taking (120 days)

The Simultaneous K_S and K_L Beams



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

Detectors



- $K_{\mathrm{L,S}} \to \pi^+\pi^-$
  - magnetic spectrometer ($\mathrm{P}_{\perp}{}^{kick} \sim 256\mathrm{MeV}/c$)
  - 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 2×2 cm^2 cells)
    - $*$ projective geometry

The 1997 Run

Sept/Oct 1997 : first Re(ε'/ε) run

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

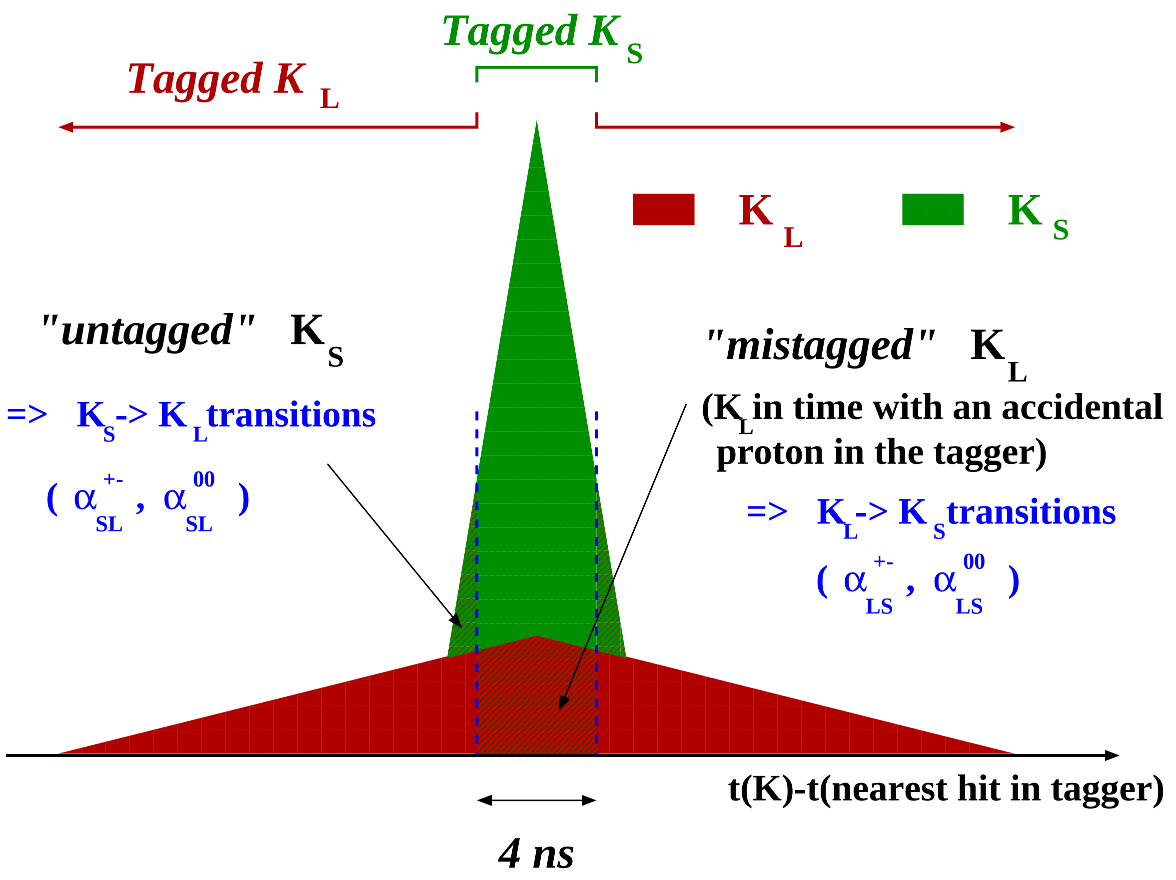
- 2/3 of nominal beam intensity
- 42 days of data taking
- 25 Tbytes of data written on tape
  - Read-out 80 Mbytes/s
  - $\sim$ 12 K events recorded per spill

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

$$\begin{cases} 70GeV < E_K < 170GeV \\ 0 < \tau < 4\ \tau_S \end{cases}$$

- Expect 4-5 10^{-4} statistical error on Re(ε'/ε)

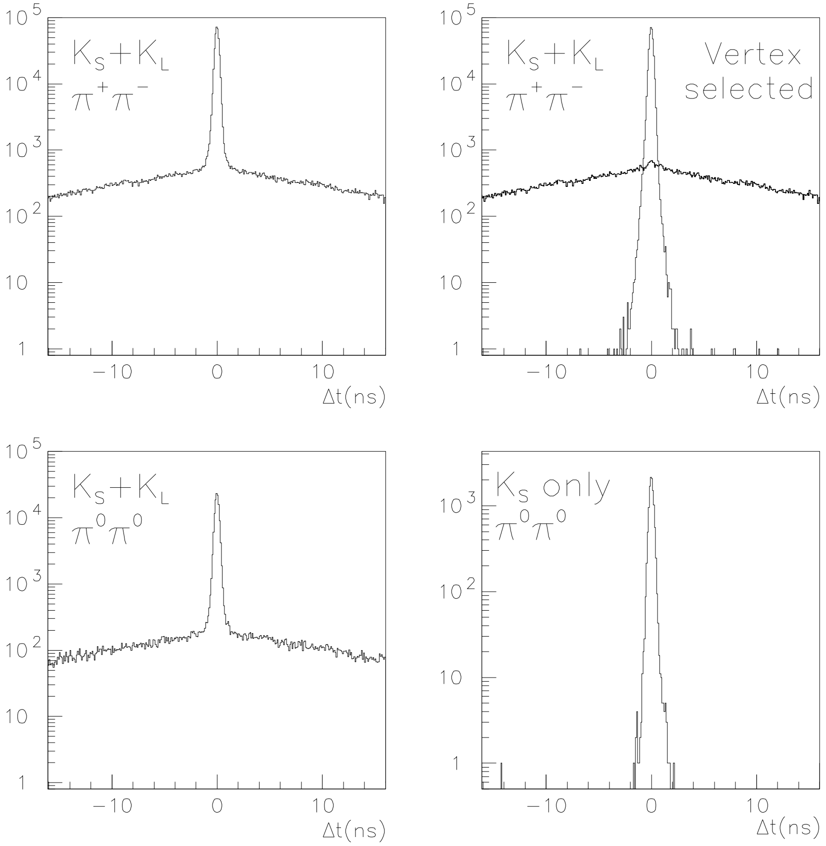
Tagging : Principle



- $\mathrm{K_L} \to \mathrm{K_S}$ transitions "dilute" the value of R
  $\Delta\mathrm{Re}(\varepsilon'/\varepsilon) \simeq .3\ \Delta({\alpha_{LS}}^{00} - {\alpha_{LS}}^{+-})$

- $\mathrm{K_S} \to \mathrm{K_L}$ transitions
  From tails in time reconstruction of decays
  $\Delta\mathrm{Re}(\varepsilon'/\varepsilon) \simeq .9\ \Delta({\alpha_{SL}}^{+-} - {\alpha_{SL}}^{00})$

Tagging : Measurements



❖ Charged mode : $\mathrm{K_L}$ and $\mathrm{K_S}$ 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 using side bands of tagging window.

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

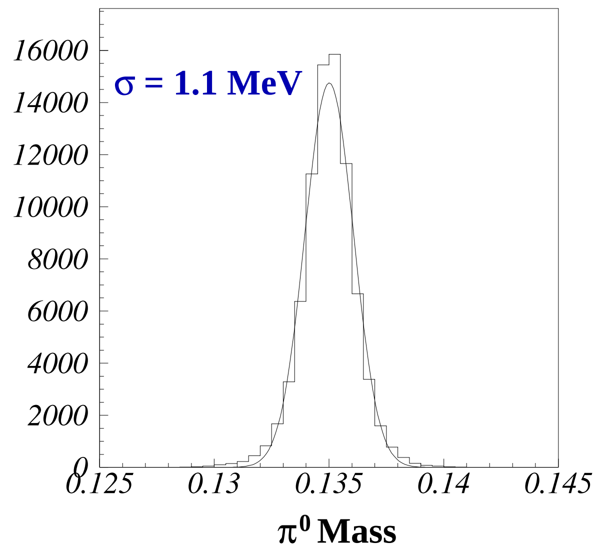
❖ $(\alpha^{00}_{SL} - \alpha^{+-}_{SL}) \leq 1 \cdot 10^{-4}$ extracted with $\mathrm{K_S}$ and $\mathrm{K_L}$ decays with conversions

The LKr 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

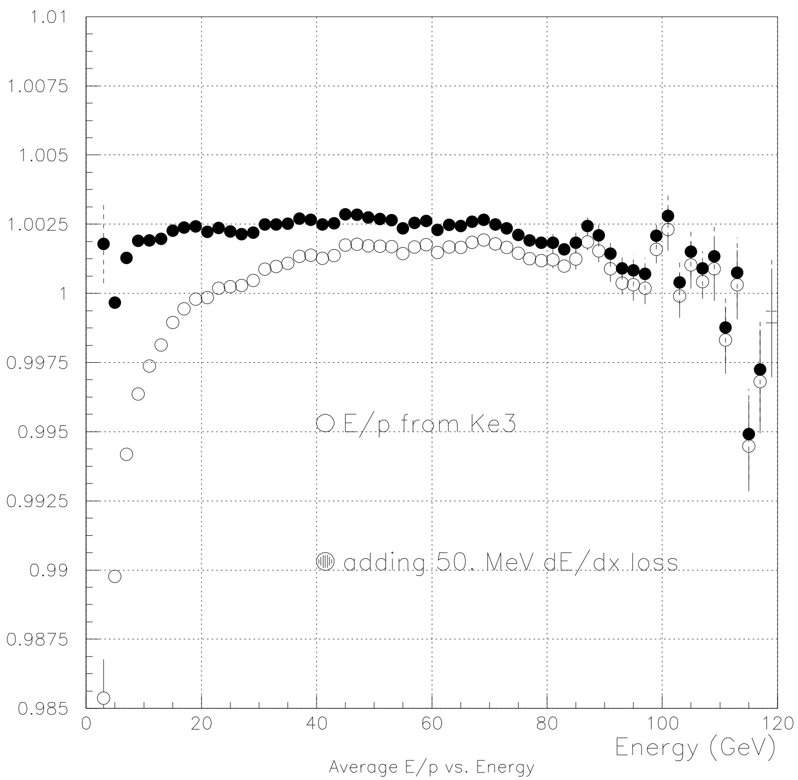
- Calibration :
  - Electronics gain checked regularly
  - 1 correction factor based on K_{e3} per cell to improve resolution

- 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

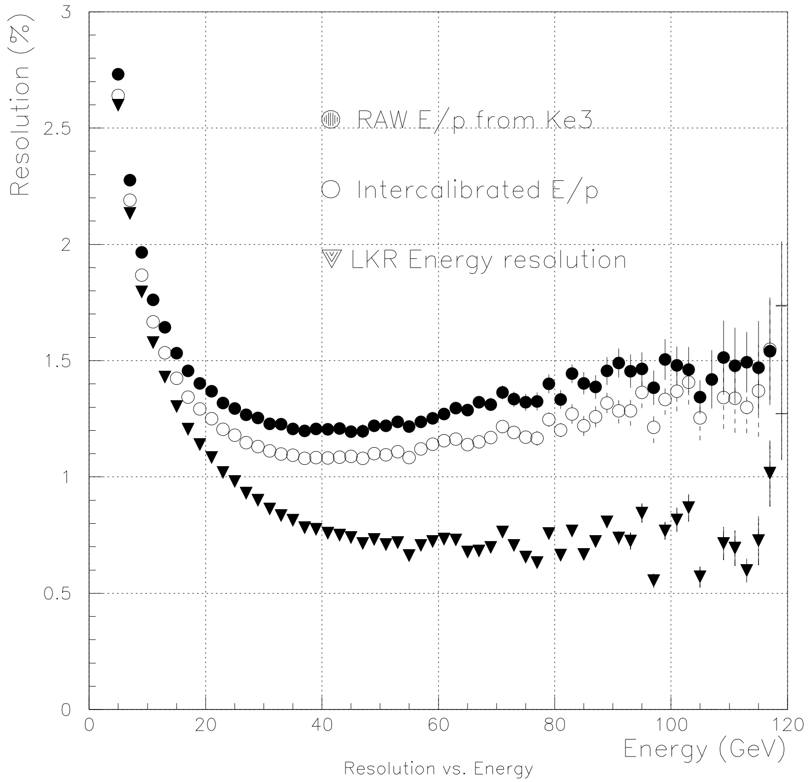


Linearity and Resolution

With electrons from K_{e3}



Average E/p vs. Energy



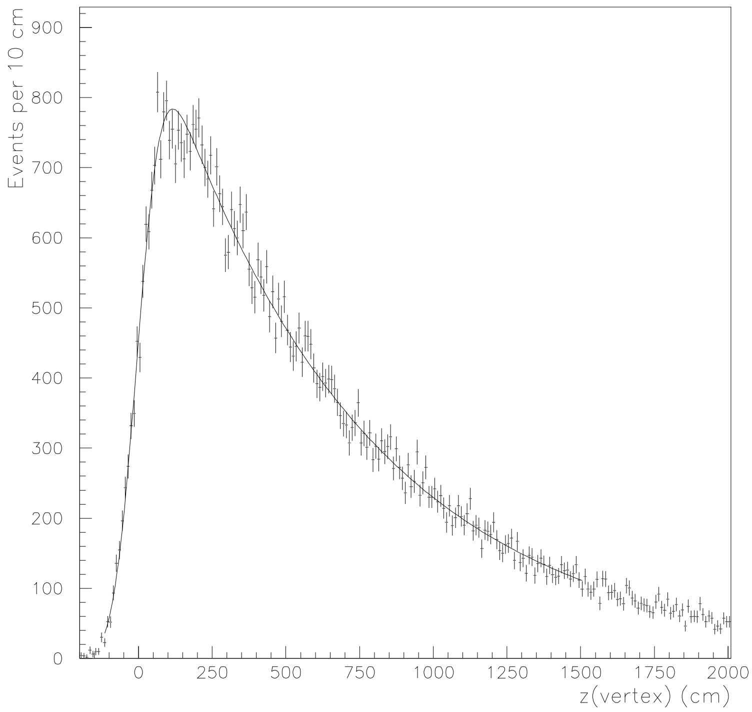
Resolution vs. Energy

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

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

Energy Scale

- Neutral energy scale $\Leftrightarrow$ Distance scale :
$$D \propto \sqrt{\sum E_i E_j \times \{(x_i - x_j)^2 + (y_i - y_j)^2\}} \;/M_K$$
- To ensure that there is no effect on the double ratio, the average Neutral distance scale should be known to a few 10^{-4}
- The energy scale is adjusted by fitting the AKS known position which defines the beginning of the $\mathrm{K_S}$ decay region



- Stability with time $\approx \pm\, 5.10^{-4}$

  (variations are 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

- Triggers efficiency
  - Charged trigger efficiency:
    - K_S : $(90.61 \pm .08)$ %
    - K_L : $(90.66 \pm .10)$ %
    - Neutral trigger efficiency $\simeq$ 99.9 %
- Backgrounds
  - Neutral mode : 3 π^0 decays - $\lesssim 1.10^{-3}$
  - Charged mode : K_{e3} and $K_{\mu 3}$ decays - $\lesssim$ .3 %
- Differential K_L -K_S accidental activity
  - studied by overlaying random events
- Acceptance corrections (slight difference in Kl and Ks beam shapes)

Conclusions from '97 data

- ε'/ε analysis in progress
- Expect ε'/ε value from '97 data with an accuracy comparable to NA31/E731 experiments

The 1998 Run

Improvements

- all HV blocking capacitors of LKr calorimeter replaced
  $\Rightarrow$ 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

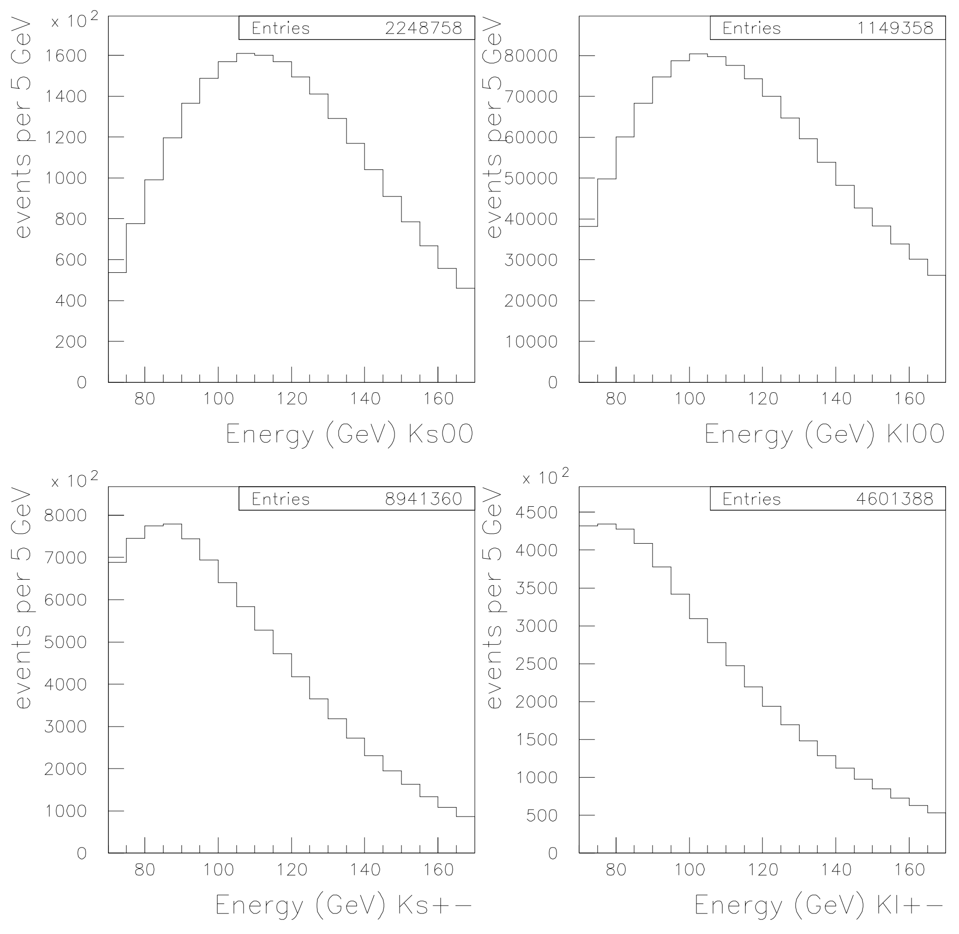
$\Rightarrow$ sustained transfer rate of 20 Mbyte/s
$\Rightarrow$ $\sim$ 30 % trigger rate increase

Achievements

- took data from mid-May until September
- $\sim 2\ 10^6\ \mathrm{K_L} \rightarrow \pi^0\pi^0$
- 75 Tbytes of data recorded and reprocessed (3 months on the CS2)
- Analysis of 98 data starting

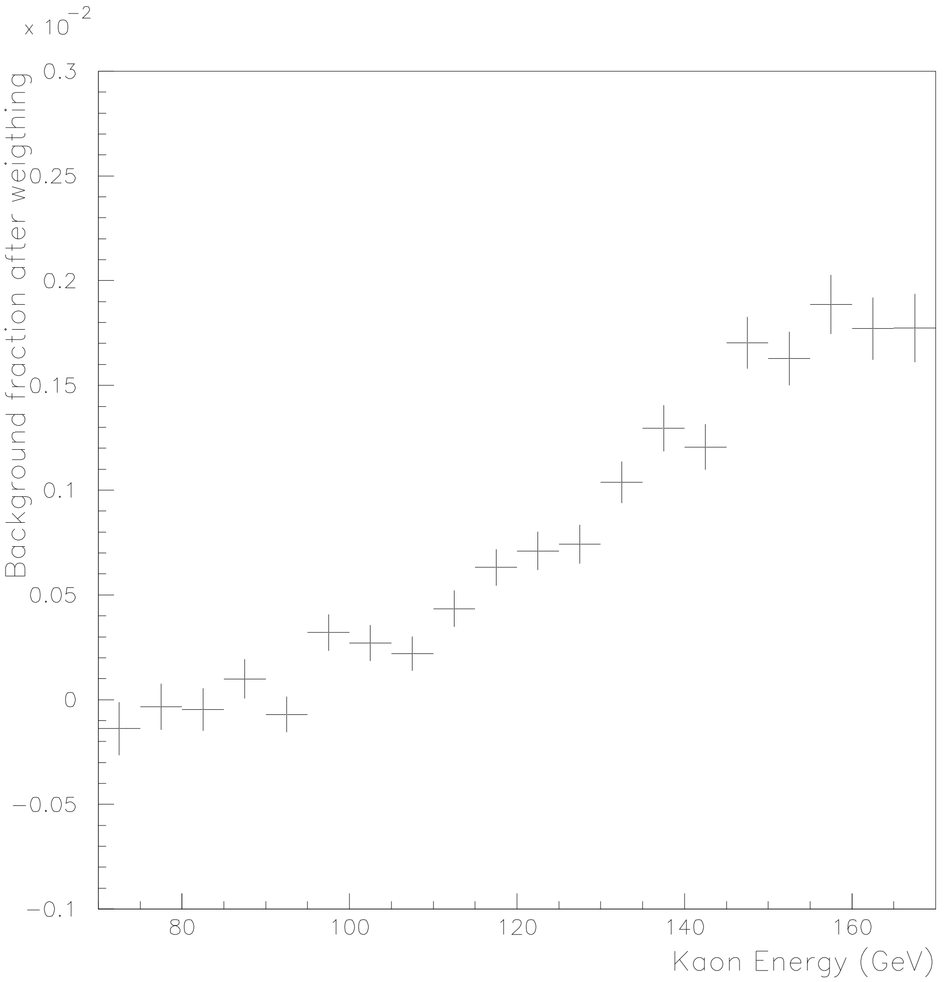
The 1998 Run

Accepted Energy Spectra



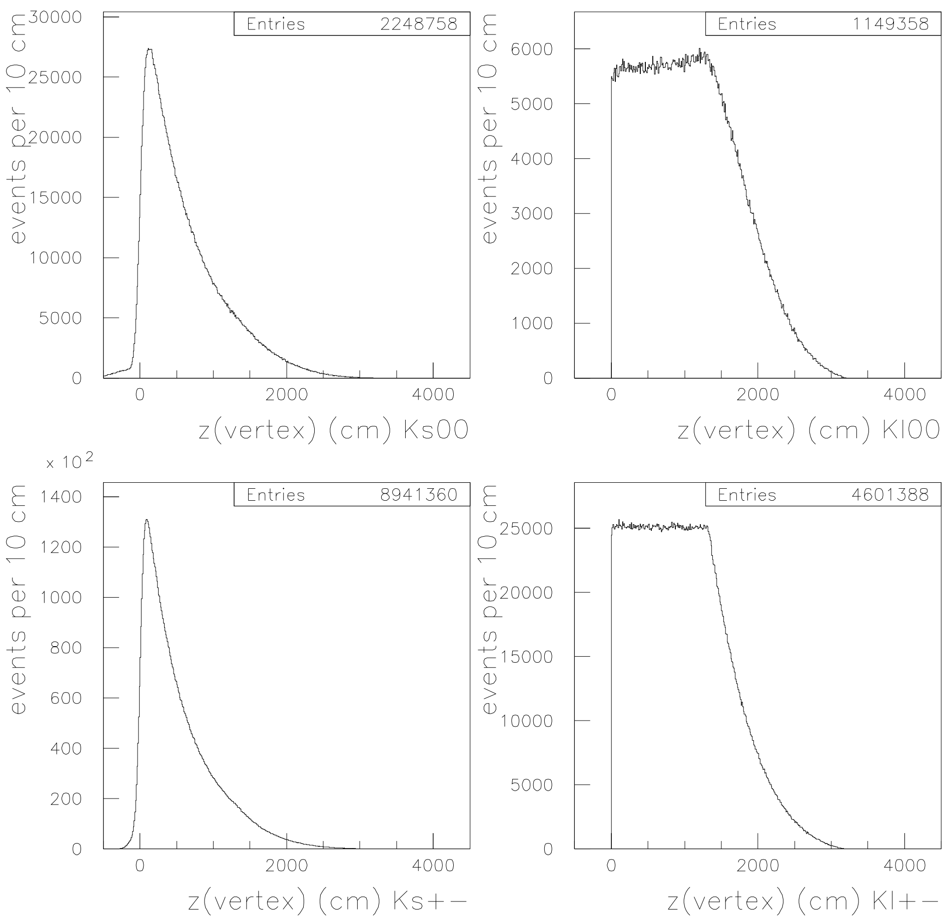
The 1998 Run

Neutral Background (preliminary !)



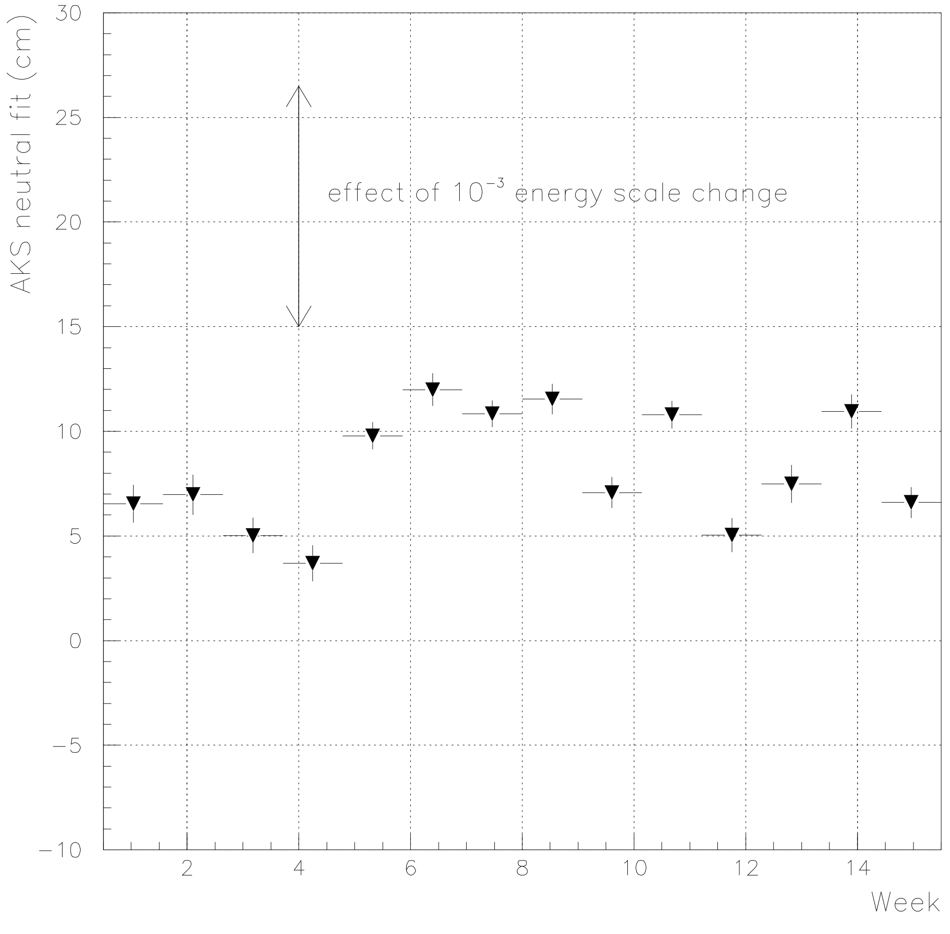
The 1998 Run

Vertex Distributions along Beam axis



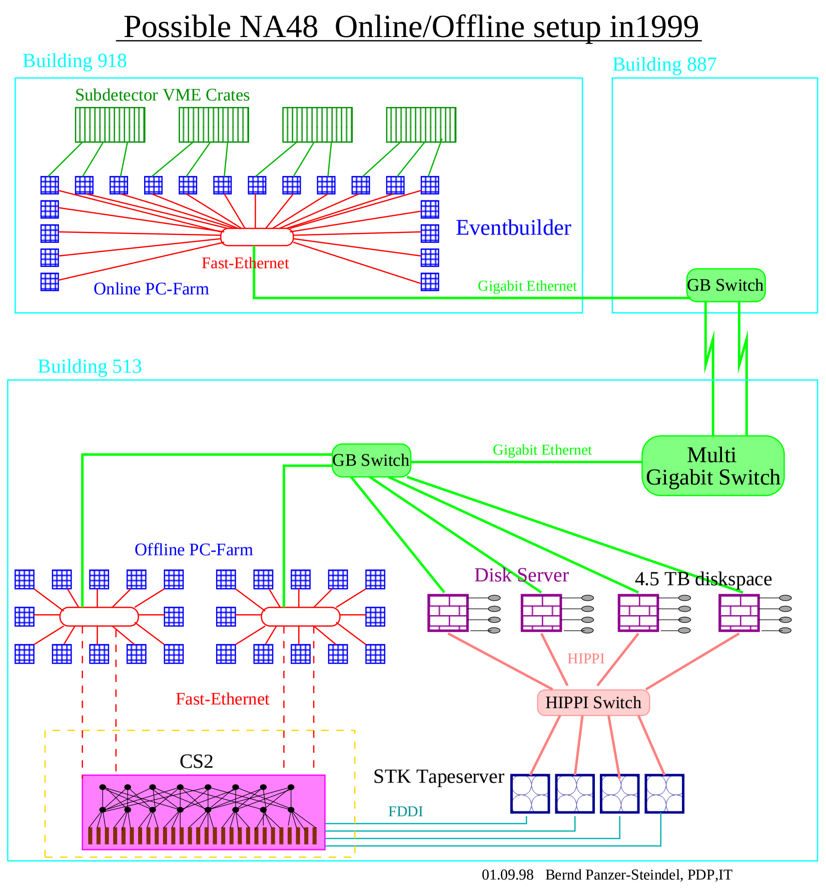
The 1998 Run

Stability of AKS fit with time (preliminary !)



The 1999 Run Preparation

- Counters of Muon Veto replaced
- Charged trigger processors upgraded from 200 MHz to 300 MHz
- Drift Chamber readout improved
- Central Data Recording : Moving from the CS2 to a PC farm + Sun disk servers



- Getting ready for recording $> 2.10^6$ K$_L \rightarrow 2\pi^0$

Year 2000

Priority : complete the $\mathrm{Re}(\varepsilon'/\varepsilon)$ measurement

- Complement statistics :

1997 $\sim$ .65 10^6 $K_L \rightarrow 2\pi^0$
1998 $\sim$ 2
1999 $\sim$ 2
(expected)

$\Rightarrow$ Total : 4.6 10^6 $K_L \rightarrow 2\pi^0$ before cuts

$\Rightarrow$ After cuts, weighting, other modes contribution :
$\Delta\mathrm{Re}(\varepsilon'/\varepsilon) \sim 1.7\ 10^{-4}$ from events statistics

$\Rightarrow$ Add systematic errors limited by statistics
(mostly Charged Trigger Efficiency) :

$\Rightarrow$ Statistical contribution to $\Delta\mathrm{Re}(\varepsilon'/\varepsilon) \sim 2.1\ 10^{-4}$
(extrapolation from 1997 studies)

Year 2000

- Complement systematic studies :

  - Effects of accidental activity :
    - Run at varying beam intensity
      up to 1.5 - 2 Nominal Intensity
      collect $\sim 2.5\ 10^6\ K_L \rightarrow 2\ \pi^0$

  - Energy Scale : more specialized runs
    Need Energy Scales in neutral and charged modes
    match to a few 10^{-4}
    - Calibration of LKr calorimeter

  - Tagging performances
    - K_S only runs

Year 2000

- **Option : K_S only Run**
  at $\sim$ 100 $\times$ Nominal Intensity on the K_S target

  – Main Motivations

    * Search for $\mathrm{K}_S \to \pi^0 e^+ e^-$ decays

    $\Rightarrow$ get (limit on) contribution of indirect CP violation for the decay $\mathrm{K}_L \to \pi^0 e^+ e^-$:

$$\mathrm{BR}(\mathrm{K}_L \to \pi^0 e^+ e^-)_{\text{mixing only}} = 3 \times 10^{-3}\, \mathrm{BR}(\mathrm{K}_S \to \pi^0 e^+ e^-)$$

    Sensitivity

    estimated (acceptance $\cdot$ cuts) efficiency $\simeq 5$ %
    $\Rightarrow$ Single Event Sensitivity : 7×10^{-7} per week
    $\Rightarrow$ Limit $\sim 5 \times 10^{-9}$ 90 % CL per week on $\mathrm{BR}(\mathrm{K}_L \to \pi^0 e^+ e^-)_{\text{mixing only}}$
    (pdg : $< 1.1 \times 10^{-6}$ (90% CL))

    * Search for $\mathrm{K}_S \to \pi^0 \gamma\gamma$

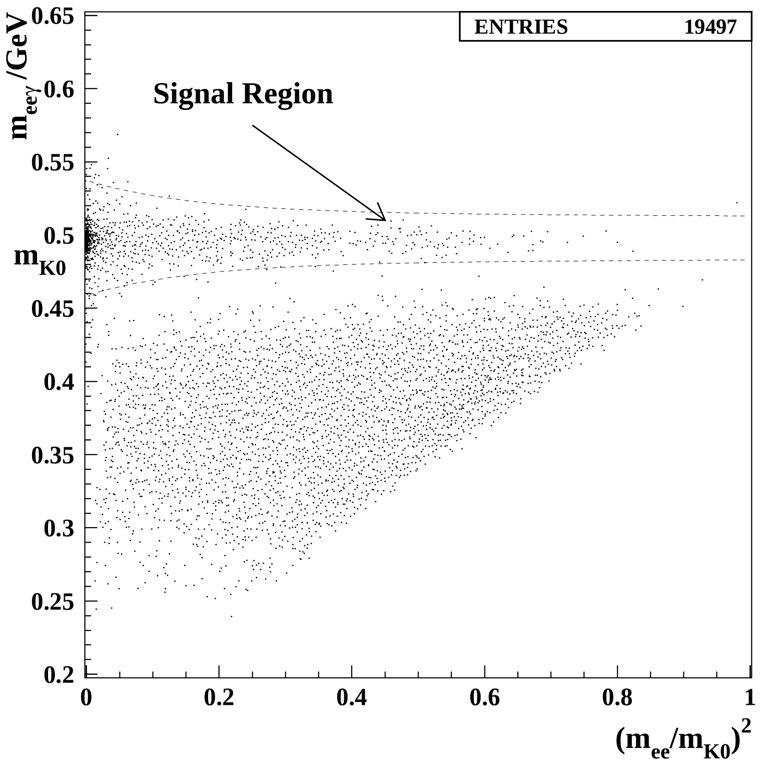
    $\Rightarrow$ Get (limit on) absorptive part of $\mathrm{K}_S \to \pi^0 e^+ e^-$

    * Measure $\mathrm{BR}(\mathrm{K}_S \to \gamma\gamma)$
      Recall pdg : $\mathrm{BR}(\mathrm{K}_S \to \gamma\gamma) = (2.4 \pm .9) \cdot 10^{-6}$
      (NA31, 69 K^0 decays - 52 K_L decays)

  – Competition : KLOE experiment

The Rare Decays – $K_L \to e^+e^-\gamma$

1997 Data Results



- $K_L \to \gamma\gamma^*, \quad \gamma^* \to e^+e^-$

$\Rightarrow$ precise measurement of the B.R. and of the parameter α_{K^*} for the $K\gamma\gamma^*$ form factor

- pdg: $BR = (9.1 \pm 0.5) \times 10^{-6}$, $\alpha_{K^*} = -0.28 \pm 0.08$

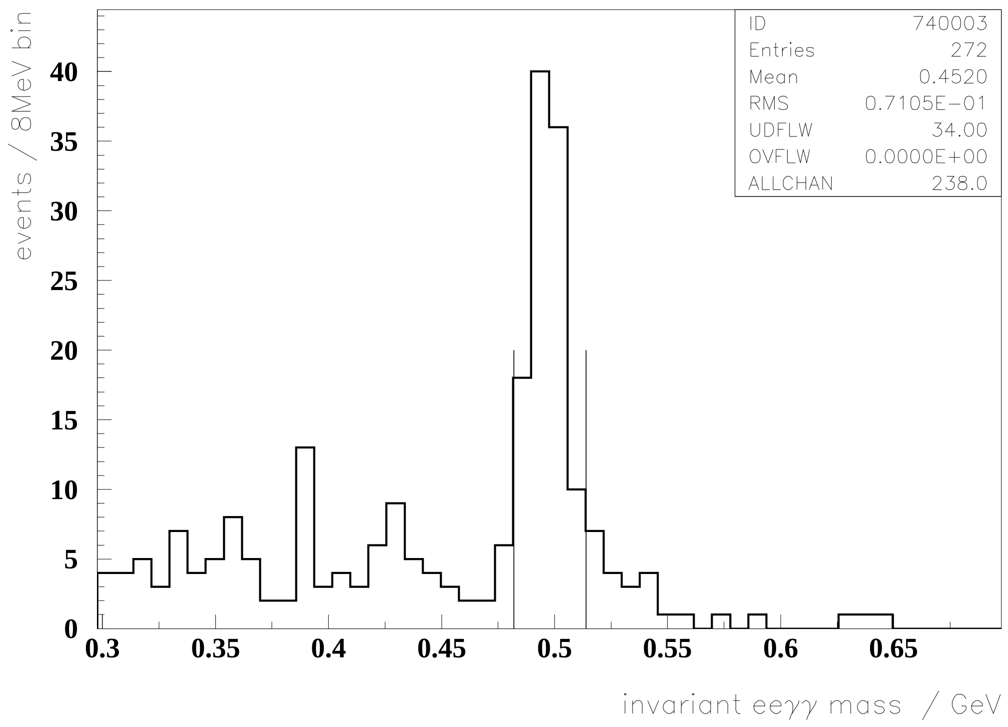
1997 DATA – PRELIMINARY RESULTS

- signal well separated from the background: 6864 events
- main background: $K_S \to \pi^0\pi^0{}_D$, K_{e3} + *accidental* γ
- total background: 10.3 ± 1.5 events

$$\boxed{\alpha_{K^*} = (-0.357 \pm 0.064^{+0.019}_{-0.014}}$$

$$\boxed{B.R. = (1.060 \pm 0.022 \pm 0.019 \pm 0.042) \times 10^{-5}}$$

The Rare Decays – $K_L \to e^+e^-\gamma\gamma$



1997 DATA RESULTS (PRELIMINARY)

- 106 $e^+e^-\gamma\gamma$ candidates in the peak

$$\boxed{BR(K_L \to e^+e^-\gamma\gamma) = (4.5 \pm 0.7 \pm 1.4) \cdot 10^{-7}}$$

$(E_\gamma > 5$ MeV and $m_{e\gamma} > 1$ MeV$)$

Beyond Year 2000

- Work in progress to address the possibility of a rare K_L decays program

- Most interesting channels :

  - $K_L \rightarrow \pi^0 e^+ e^-$
    - * SM expectation in the range 10^{-12} - 10^{-11}
    - * Expected Competition SES $\sim 10^{-11}$
    - * Background : $K_L \rightarrow e^+ e^- \gamma\gamma$

    $\Rightarrow$ NA48 preliminary measurements of BR : see plots
    - * With 1 % (acceptance $\cdot$ cuts) efficiency : Signal/Background $\sim 1/10$!

  - $K_L \rightarrow \pi^0 \mu^+ \mu^-$
    - * phase space $\Rightarrow$ BR / 5 X lower than previous channel
    - * Expected Competition SES $\sim 2\ 10^{-11}$
    - * Background seems less severe

- Other channels under study : statistics needed, competition

  - $\pi\pi ee$
  - $\pi^0 \gamma\gamma$
  - $ee\gamma$, $\mu\mu\gamma$
  - $eeee$, $ee\mu\mu$

Beyond Year 2000

- Possible Beam Upgrade :
  - No K_S beam
  - Open K_L beam acceptance from $\pm$ .15 to $\pm$ .25 mrad
  - 450 $\rightarrow$ 400 GeV protons $\Rightarrow$ duty cycle 2.3/14.4 to 5/19.2
  - Increase beam intensity in 2 stages :
    - * 2001 : 1.5 10^{12} ppp $\rightarrow$ 2.4 10^{12} on T10
    - $\Rightarrow$ altogether instantaneous rate in detectors x 2
    - * after 2001 : 1.2 10^{13} ppp on T10 (another factor 5)
  - Extended fiducial decay region and momentum range for rare decays

$\Rightarrow$ about 10^{12} K decays per year between collimator and detector :

i.e. an increase of about 70 in accepted K decays for

an instantaneous rate increase of about 10 in the detectors

- Use of charged K beams also under consideration to search for direct CP violation in charged K decays

- Considered Detector Upgrades
  - Trigger, readout of some of the detectors, ...
  - Change gas mixture of the drift chambers
  - Add a TRD

Conclusions

- $\mathrm{Re}(\varepsilon'/\varepsilon)$ analysis on 97 data in progress.

- $\sim$ 3 times more data have been recorded in 98, analysis is starting

- 1999 data taking for $\mathrm{Re}(\varepsilon'/\varepsilon)$ in preparation

$\longrightarrow$ Central Data Recording Upgrade

- NA48 wishes to take data in year 2000

  * to complement the statistics

  * to perform additional systematics checks

$\Rightarrow$ achieve a precision of 2 10^{-4} on $\mathrm{Re}(\varepsilon'/\varepsilon)$

- Study of a rare and/or charged K decays program beyond year 2000 in progress