# The NA48 Experiment at the CERN SPS

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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

# Outline

- The measurement
- The beams
- The detector
- The 1997 Run
  - Performance of the detector
  - Charged and Neutral modes
  - Statistics
- The 1998 Run
  - Detector improvements
  - Current Status
- Conclusions

# The Measurement

**aim** determine the "direct CP violation" parameter $\mathrm{Re}(\varepsilon'/\varepsilon)$ in the system $K_{L,S} \to \pi\pi$, with an accuracy of $\sim 2 \times 10^{-4}$, using the double ratio method:

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

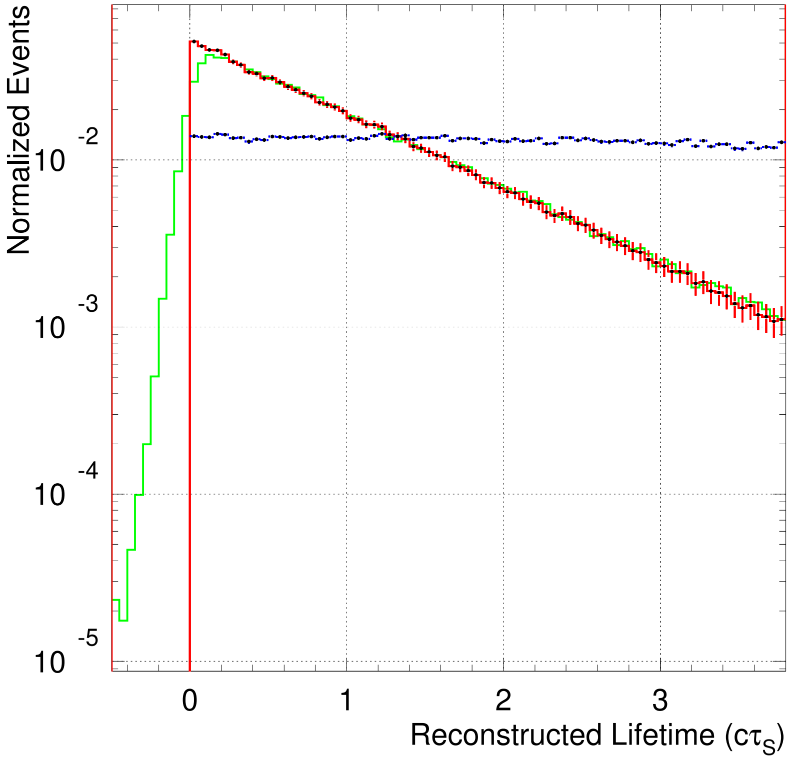
**method** The four $K^0$ decay modes, $K_{L,S} \to \pi^0\pi^0$, $K_{L,S} \to \pi^+\pi^-$, are measured

- concurrently in the same fiducial volume,
- with almost collinear K$_L$ and K$_S$ beams,
- tagging the proton which produces the K$_S$.

☞Minimal corrections required

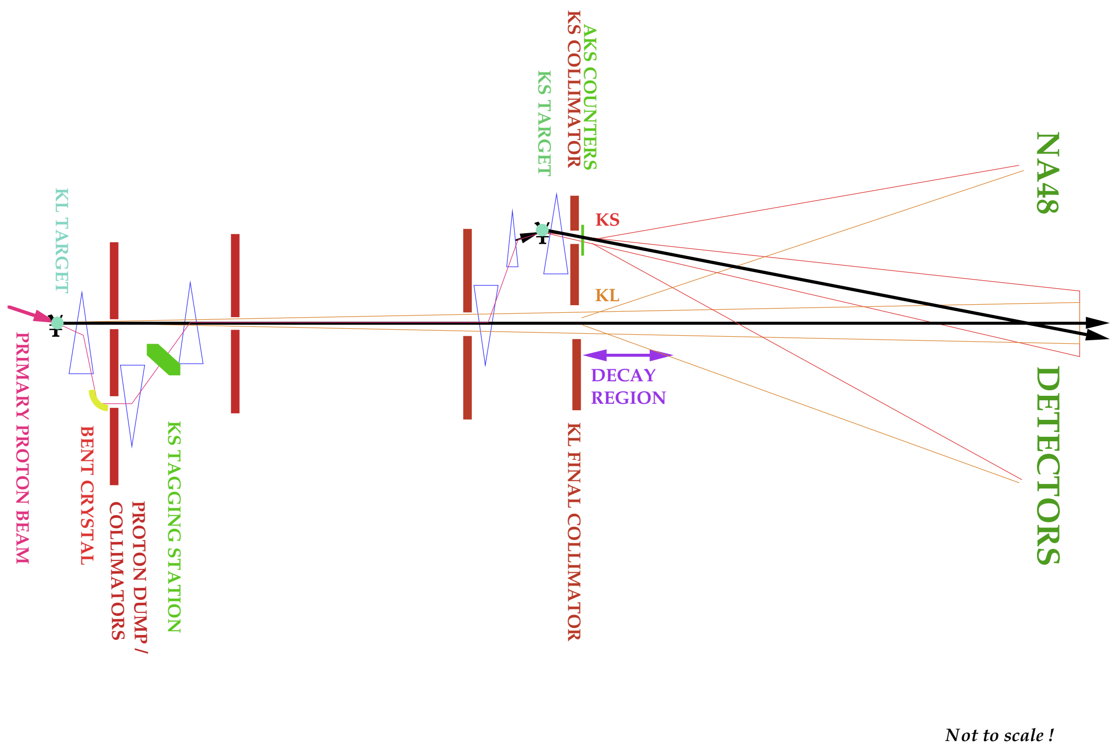
**statistics** to achieve the required accuracy, few $10^6$ $K_L \to 2\pi^0$ decays need to be collected.
This decay modes has the lowest B.R. $\simeq 10^{-3}$, hence dominates the statistical uncertainty of the result.

# The Method




- R computed in energy bins.
- Lifetime weighting makes the $K_L$ and $K_S$ vertex distributions identical (equalize proper time distributions).
- KS and KL beams tuned to produce similar decay spectra.
- The effective fiducial volume is $\sim 3.5\ c\tau_S$ long ($19\ m$ at $100\ GeV/c$) same for KL and KS
- The acceptance $A_{L,S}(z,p)$ as a function of the longitudinal decay position and $p$ cancels out in $z$

# Kl and Ks Beams

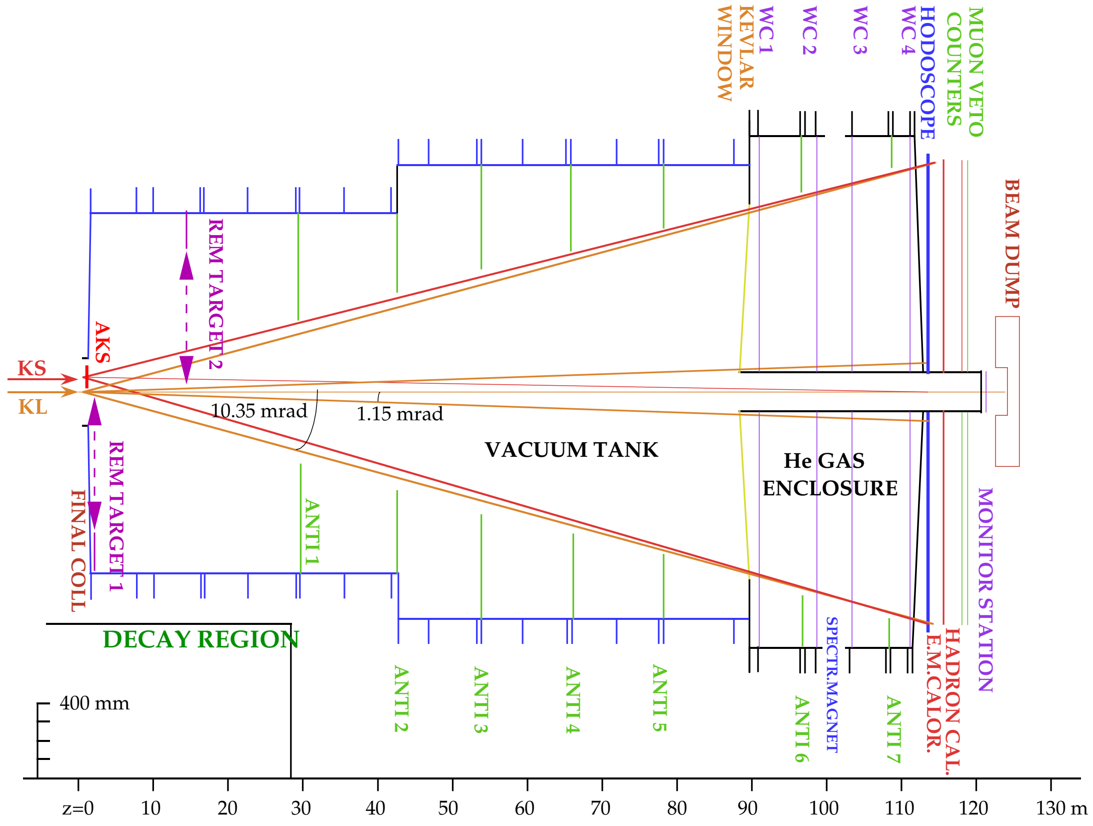



Two simultaneous and almost collinear neutral beams converge towards the NA48 calorimeters with an angle of 0.6 mrad.

**KL beam** is produced from a 450 GeV, $1.5 \times 10^{12}$ ppp, SPS proton beam.

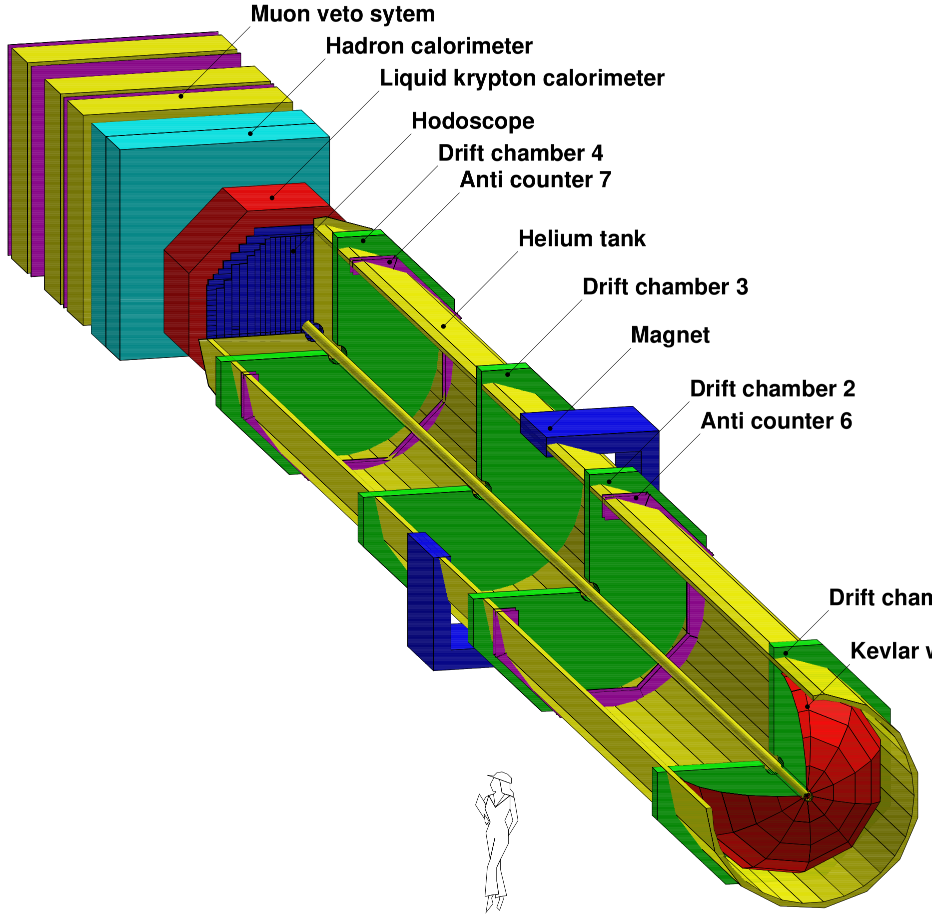
**KS beam** is produced splitting off a small fraction of the primary proton beam using a bent crystal. Protons impinging on the KS target are individually tagged.

# The Decay Volume




400 $m^3$ evacuated volume, only first 25-30m as common fiducial volume for KS and KL decays

# The Detector




**charged decays** are reconstructed by a magnetic spectrometer

**neutral decays** are reconstructed by a quasi-homogeneous Liquid Krypton e.m. calorimeter

# Triggers

## The $\pi^+\pi^-$ Trigger

**Level 1** hodoscope and $E_{TOT}$ from calorimeters

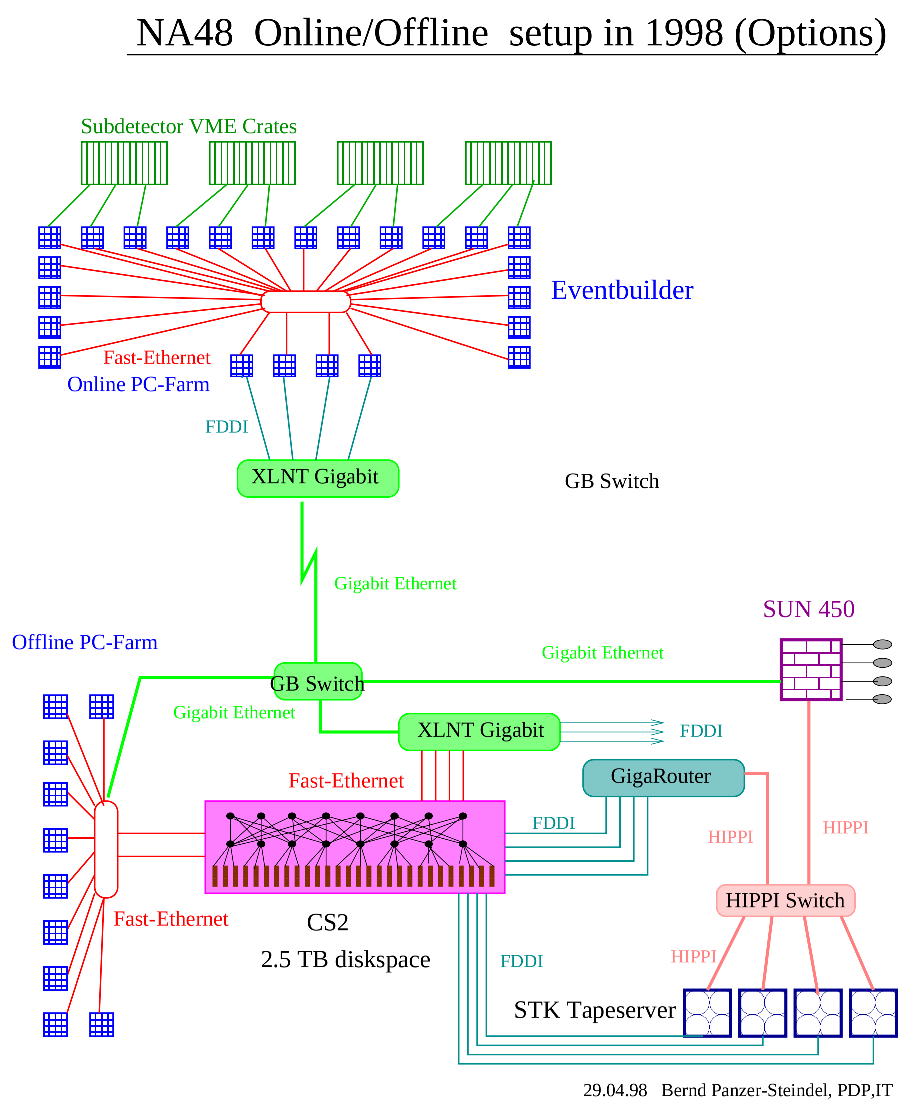
**Level 2** 32 microprocessors farm for kaon vertex and mass reconstruction

- efficiency 91%, 97 run; error on $\mathrm{Re}(\varepsilon'/\varepsilon)$ few $\times 10^{-4}$
  98 run 95%
- input rate 70 KHz; output rate 2 KHz

## The $\pi^0\pi^0$ Trigger

- fast synchronous 40 MHz e.m. calorimeter reconstruction
- cuts on E, COG and proper-time of the K, number of peaks
- fully pipelined (128 steps 40MHz), zero dead time
- 99.88% efficient for both $K_S$ and $K_L$
- input rate $\sim 1$ MHz (LKR activity); output rate 2 KHz

# Data Handling




**event building** on-line PC farm

**L3 filtering, online production** 128 procs Meiko CS-2

**Central Data Recording** 2.5 TB disk, STK tape robot

**1997** 12K events/burst, 12 MB/s transfer rate, 25 TB of data written

**1998** 18K events/burst, 18 MB/s transfer rate, 70 TB of data written

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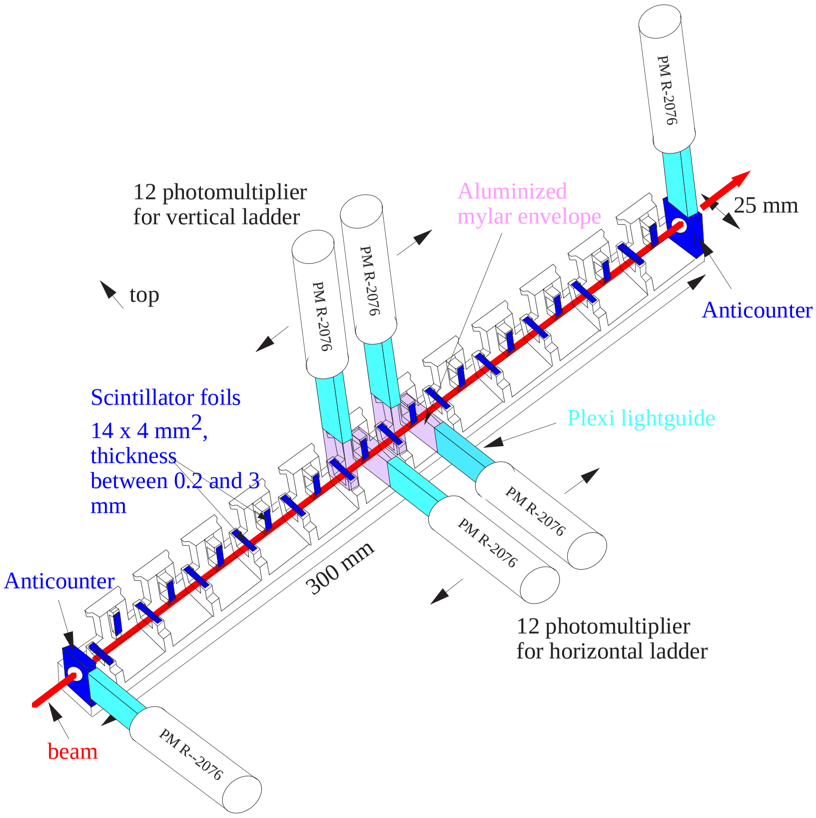
# Run 1997 - The tagger detector

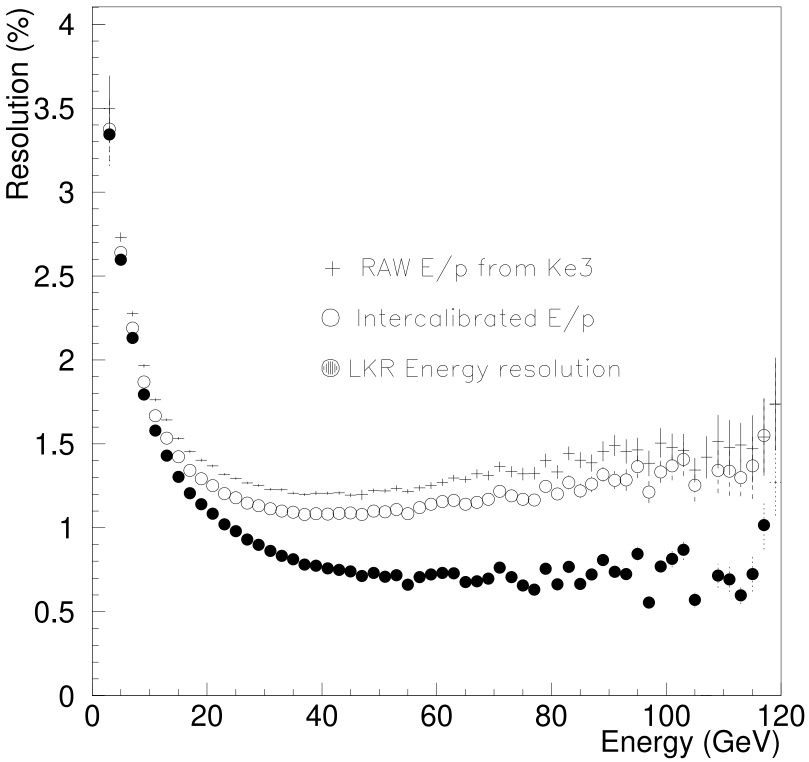



Layout of the tagging detector

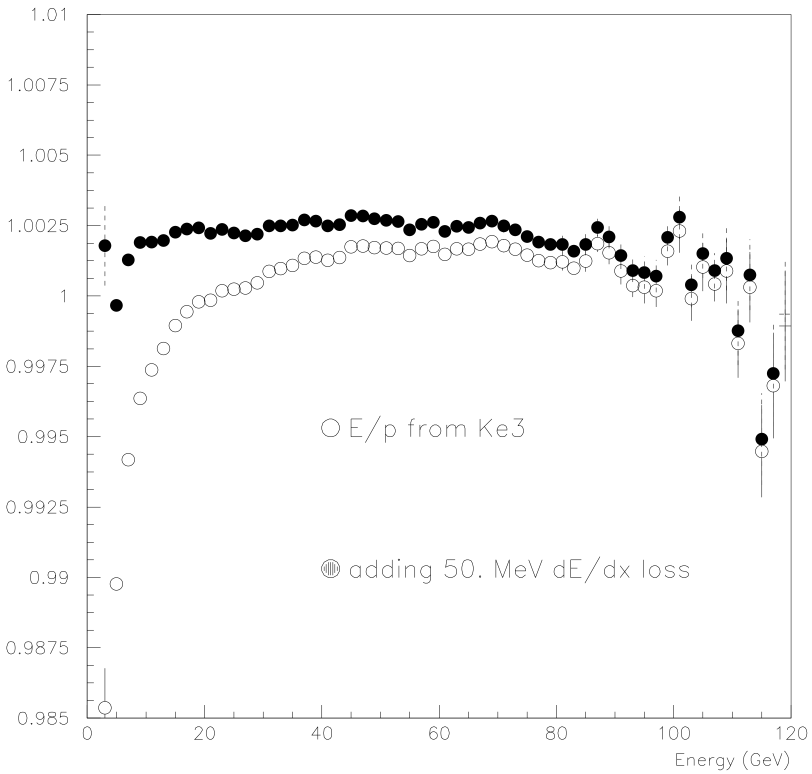
- Two ladders of 12 staggered scintillating counters
- tickness $200 - 3000\mu m$ $\Rightarrow$ individual counting rate $1 - 2MHz$
- system mounted on support with three remotely controlled independent movements $\Rightarrow$ *alignment*
- $0.01X_0$ , 300-400 photoelectons light yield
- time resolution $\sim 150\ psec$ both for individual counters and for tagging system

# The Liquid Krypton Calorimeter

# Run 1997 - Calorimeter Performance

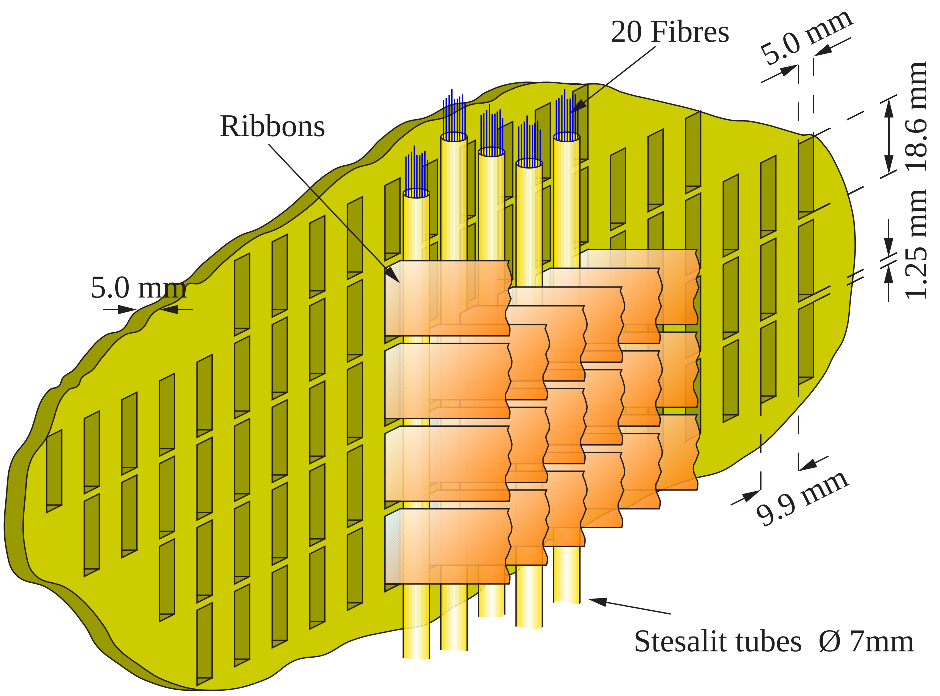



Energy Resolution




Linearity

# Run 1997 - The Neutral Hodoscope




The structure of the Neutral Hodoscope

- plane of bundles of scintillating fibers at $\sim 9.5X_0$ (shower maximum) in Liquid Kripton
- $1\ mm$ diameter fibers, 512 bundles, $\sim 20$ fibers per bundle
- 32 read-out channels, PM Hamamatsu R1355

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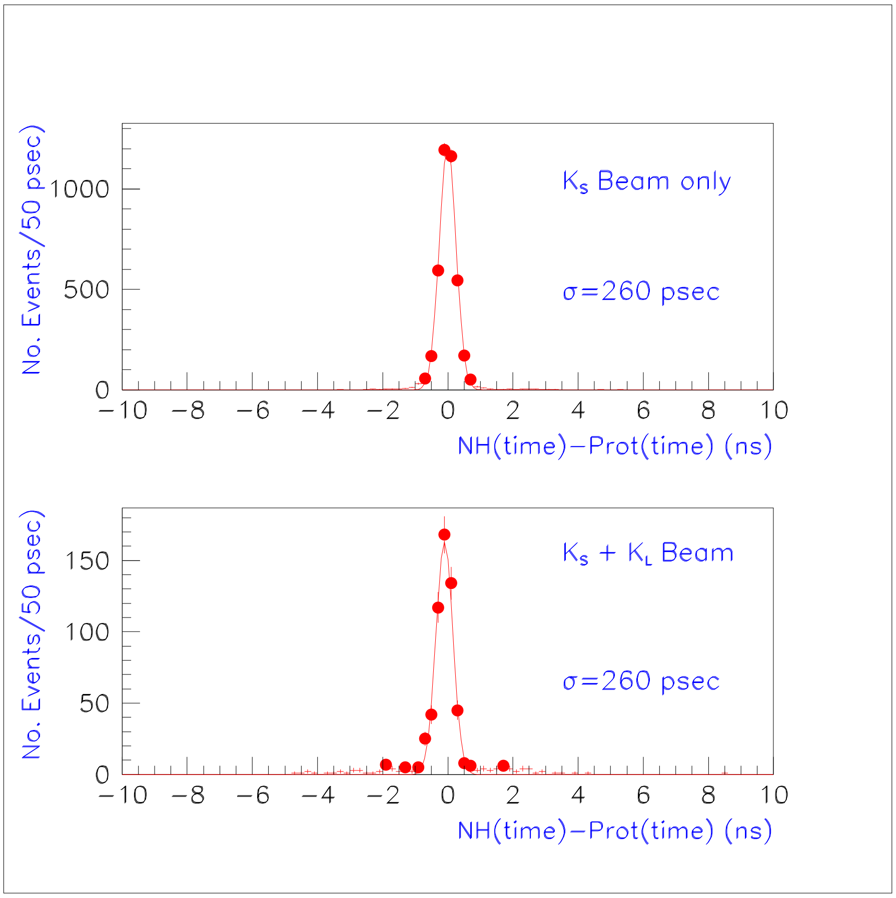
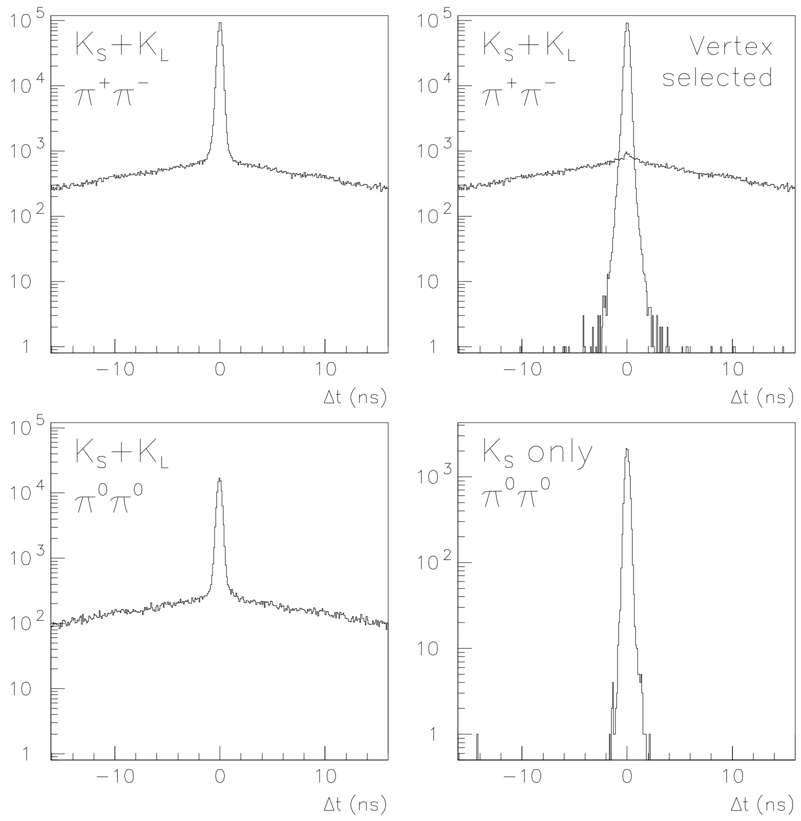
# Run 1997 - Neutral Hodoscope Performances




Time resolution for the event time given by the Neutral Hodoscope

# Proton Tagging




**Δ t** = Event time in detector minus proton time in tagger

- neutrals $\Delta t_N = t_{LKr/Nhod} - t_{tag}$
- charged $\Delta t_C = t_{CHod} - t_{tag}$

**KS⟶KL** $\alpha^{SL}$ tagging inefficiency.

$\alpha_{00}^{SL} < 2 \times 10^{-4}$ measured with KS-only runs, cheked with Dalitz

$\alpha_{+-}^{SL}$ measured to $10^{-4}$ (vertex position)

**KL⟶KS** $\alpha^{LS} \sim 11.5\%$ KL with accidental hit

$\alpha_{00}^{LS}$ from $\pi^0\pi^0\pi^0$ events

$\alpha_{+-}^{LS} \approx 10^{-4}$ (vertex position)

$\delta(\varepsilon'/\varepsilon) < 10^{-4}$



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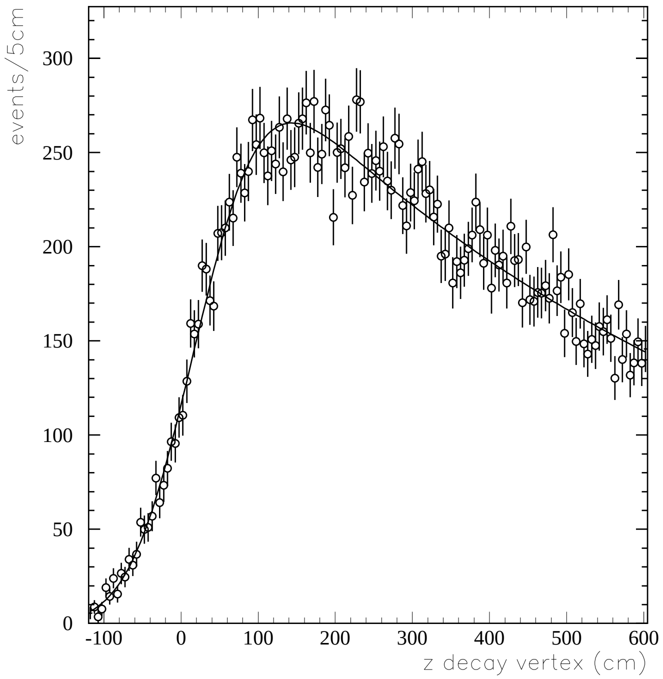
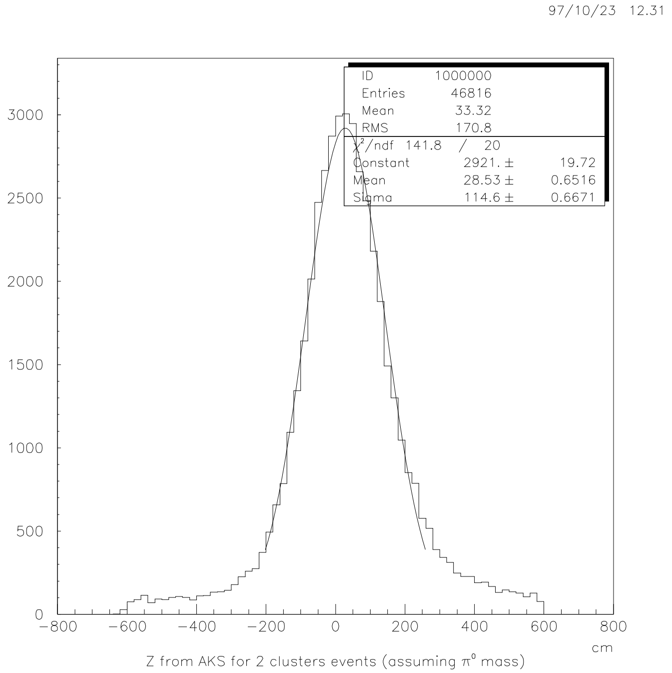
# Run 1997 - Energy scale



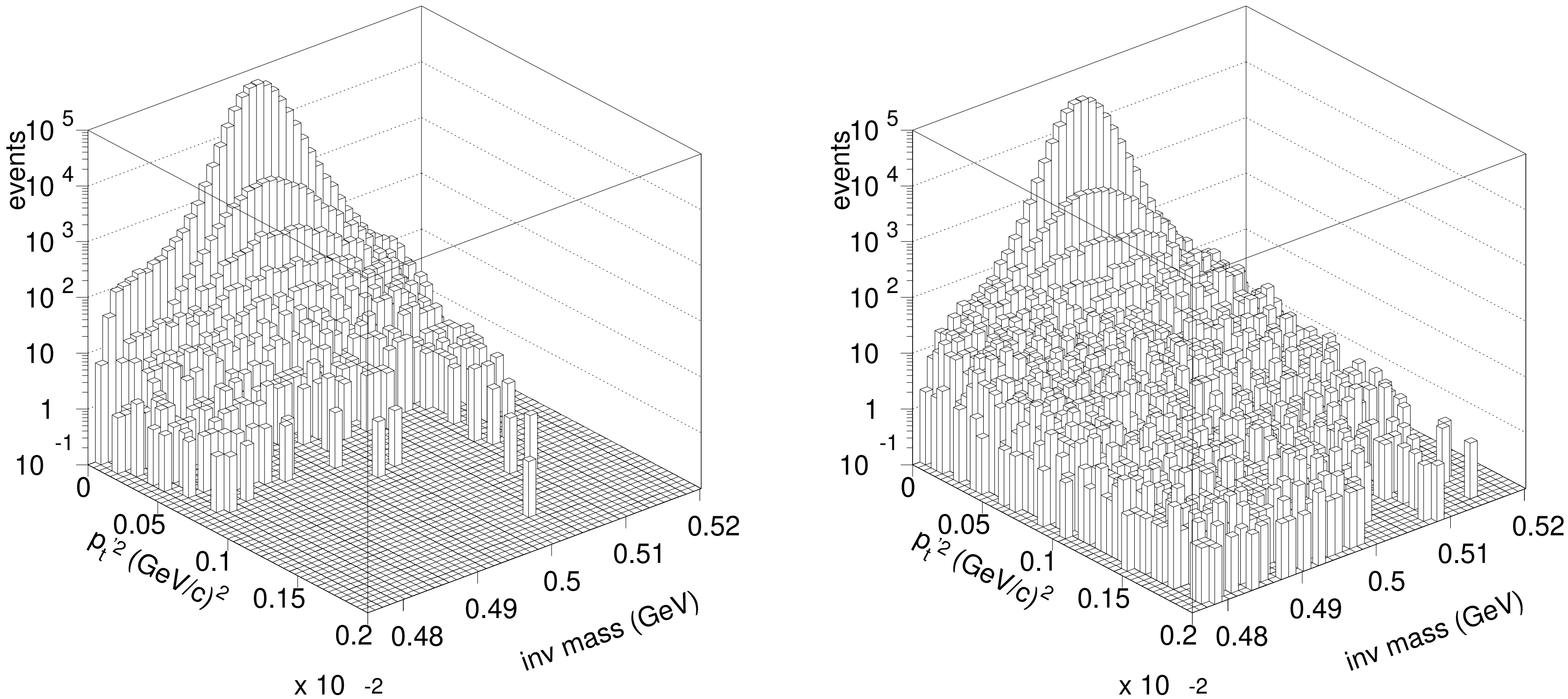




- The relative scale of reconstructed energies for $\pi^0\pi^0$ and $\pi^+\pi^-$ events has to be adjusted to $\sim 2 \times 10^{-4}$ precision
- Use charged vertex as reference, adjust neutral vertex to it
- To minimize systematical errors use:

$\Rightarrow$the upstream edge of $K_S$ exponential vertex distribution

$\Rightarrow$ the narrow peak of $\pi^0 \to \gamma\gamma$ or $\eta \to \gamma\gamma$ events produced in special runs ($\pi^-$ beam)

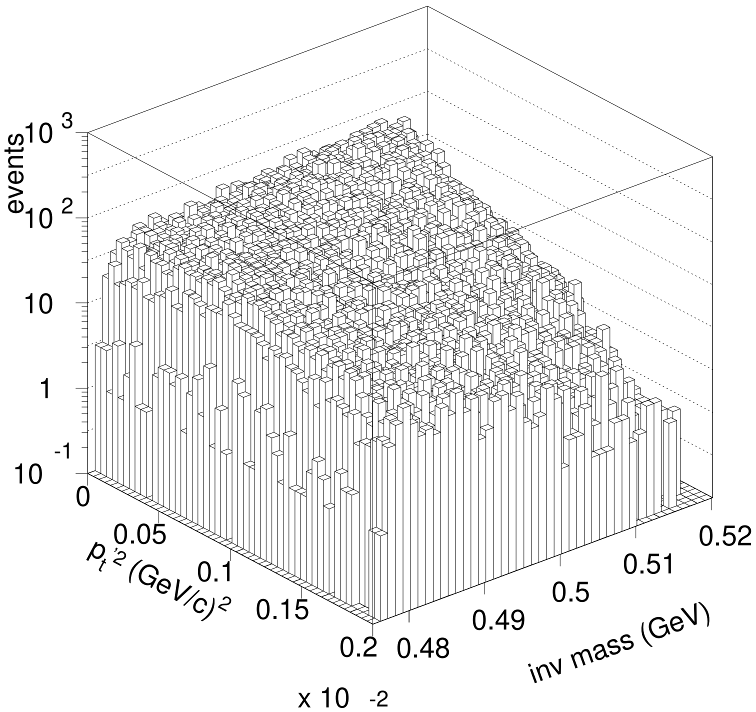
# Run 1997 - Charged mode



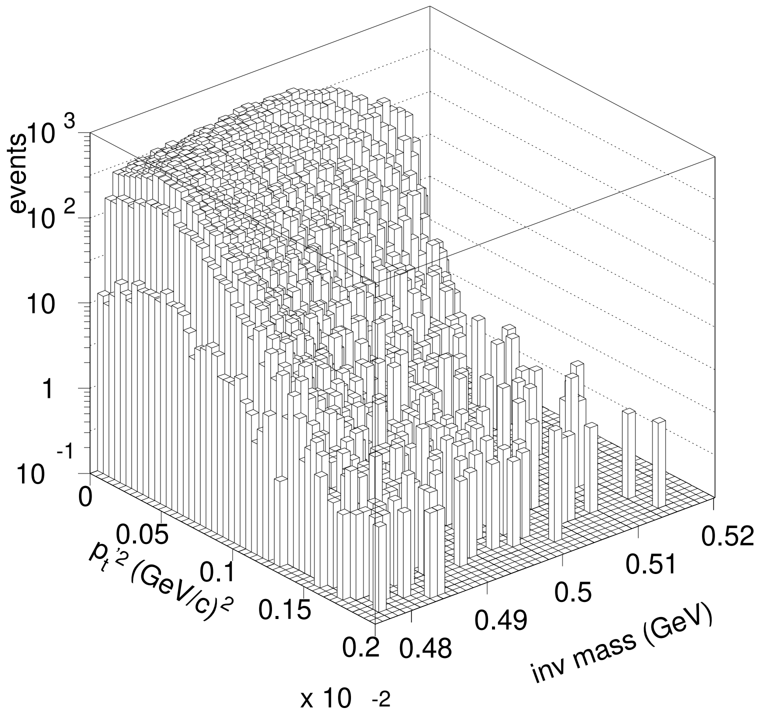

$K_S \to \pi^+\pi^-$ 'signal'

$K_L \to \pi^+\pi^-$ 'signal + background'

# Run 1997 - Charged mode - background




$K_L \to \pi e \nu (K_{e3})$

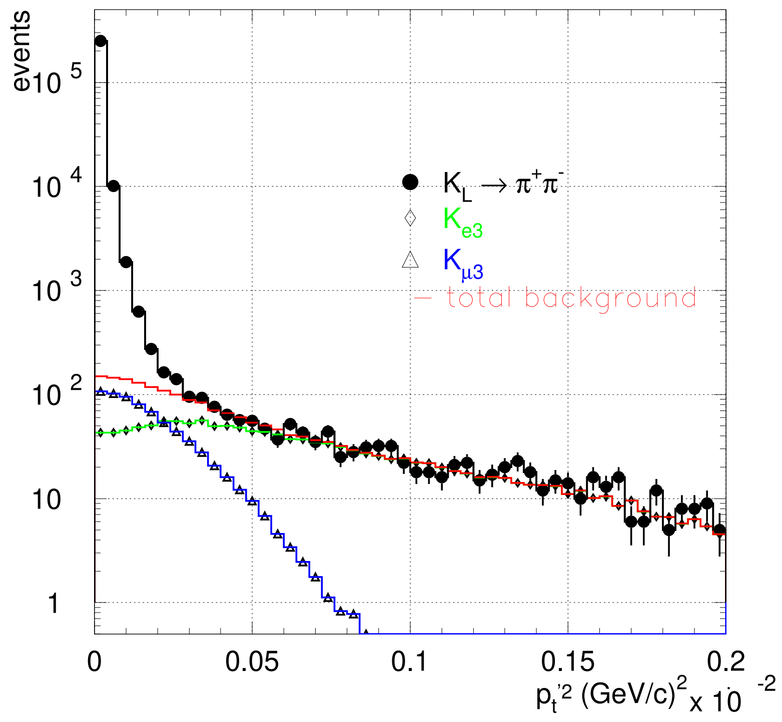



$K_L \to \pi \mu \nu (K_{\mu 3})$

- Control region is defined in $(p_t'^2, m_{\pi\pi})$
- Data fitted by $\alpha S(\pi\pi) + \beta B(K_{e3}) + \gamma B(K_{\mu 3})$

☞ functional form of subtracted background is taken from data

# Run 1997 - Charged background subtraction



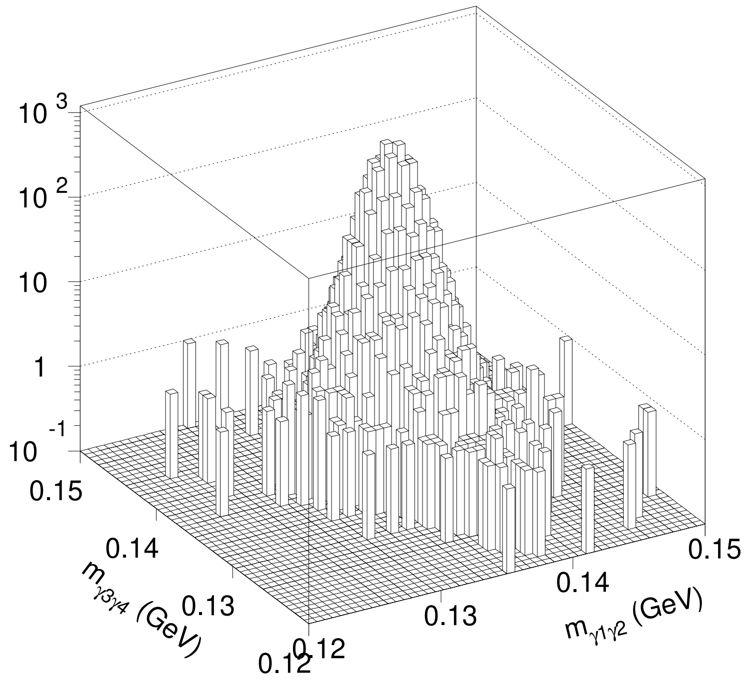

## Example - Preliminary

- Control region:
  - $p_t'^2 > 400(MeV/c)^2$
  - $m_{\pi\pi} = m_K \pm 18MeV/c^2$
- Signal region:
  - $p_t'^2 < 200(MeV/c)^2$
  - $m_{\pi\pi} = m_K \pm 7.5MeV/c^2$

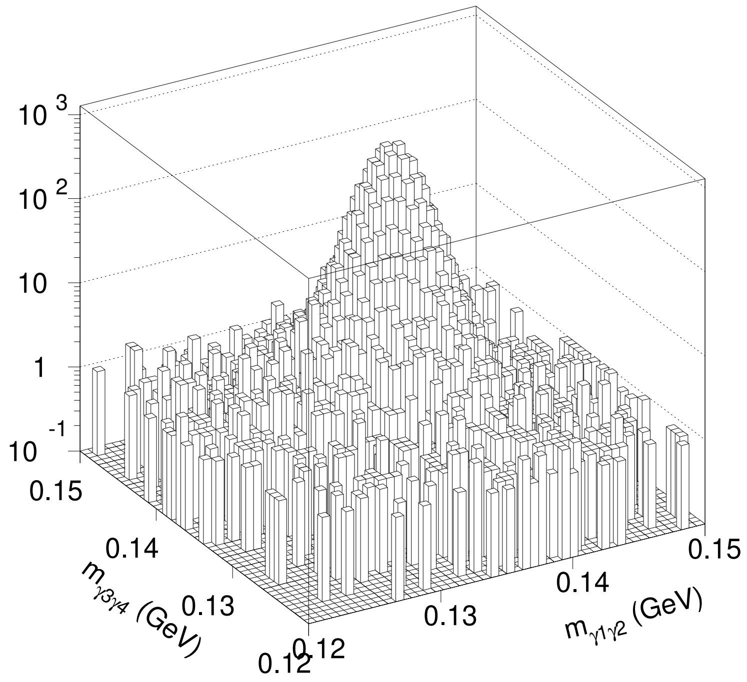
numbers in signal region:
- 264412 $K_L$
- 230 ± 13 $K_{e3}$
- 454 ± 89 $K_{\mu3}$

☞ Background to be subtracted $(2.6 \pm 0.4(stat)) \times 10^{-3}$

## Run 1997 - Neutral background subtraction



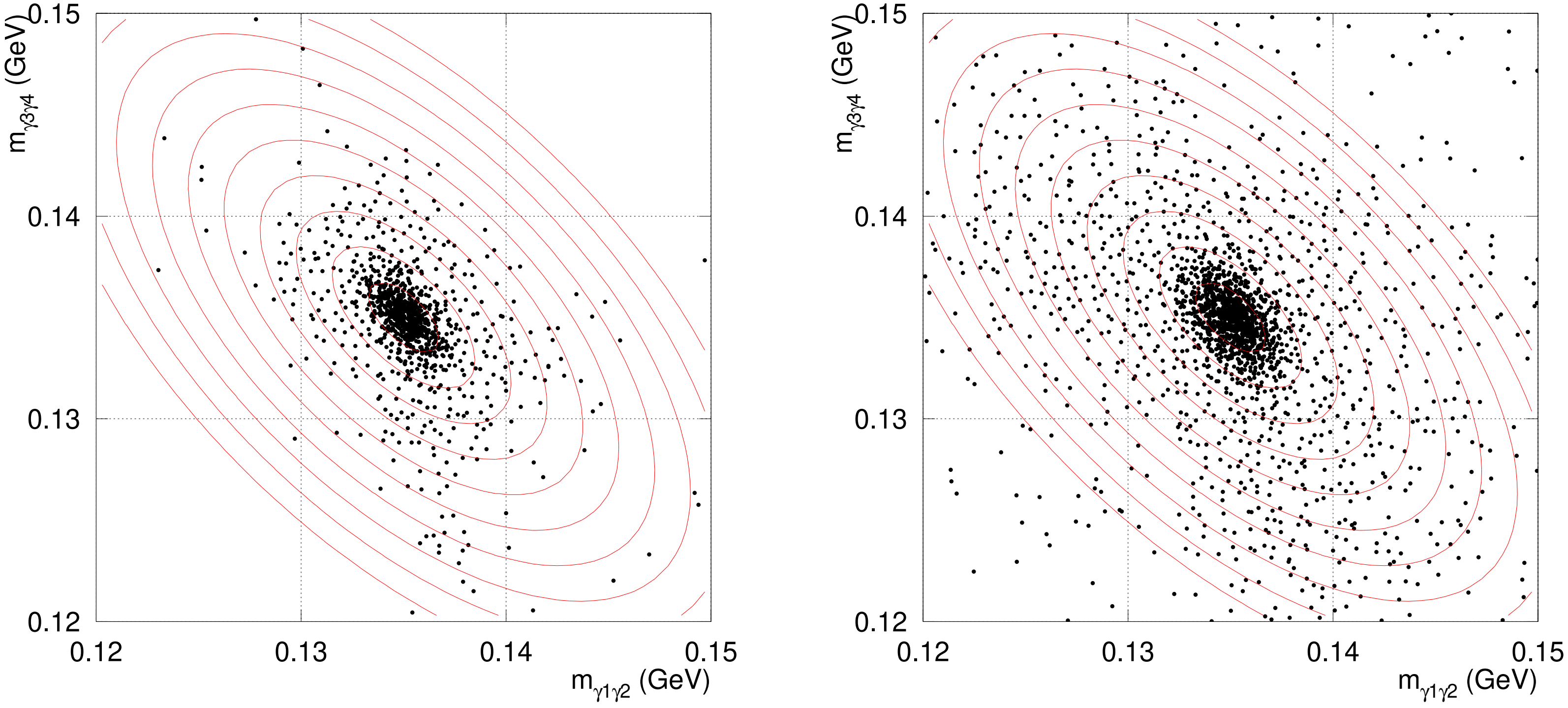

$K_S \to \pi^0\pi^0$




$K_L \to \pi^0\pi^0$

- Background to $K_L \to 2\pi^0 \to 4\gamma$ is $K_L \to 3\pi^0 \to 6\gamma$ with 2 $\gamma$ 's lost
- Suppress background: 4 clusters in time, energy centre-of-gravity
- Impose $m_K$ to find $z_v$, use $z_v$ to find best $\chi^2$ paring of $\gamma$ 's to give $m_{\gamma\gamma} = m_{\pi^0}$

# Run 1997 - Neutral mode Ellipse cuts




$K_S \to \pi^0\pi^0$ $\qquad$ $K_L \to \pi^0\pi^0$

- Subtract background in elliptical $\chi^2$ rings in the $m_{\gamma_1\gamma_2}$ - $m_{\gamma_3\gamma_4}$ plane
- Background level to be subtracted
  $3 \times 10^{-3}$ unweighted
  $1 \times 10^{-3}$ weighted

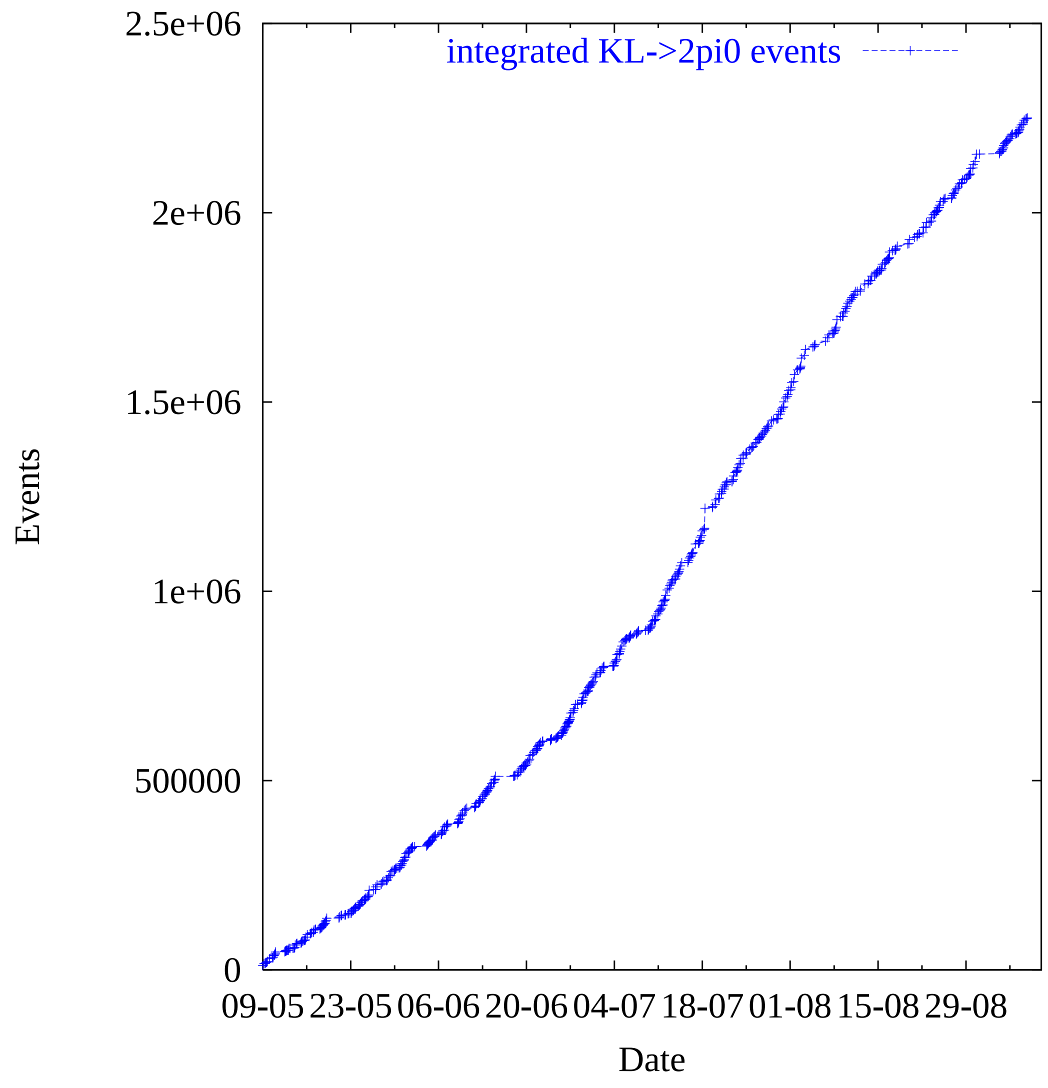
# Run 1997 - achievements

- Installation and commissioning of the entire Read/Out and Neutral Trigger electronics of the Liquid Krypton calorimeter (13 000 channels).
- Stable operation at 1.5 kV due to capacitor problems (1 column, 4 cm wide, without high voltage).
- DAQ and triggering systems integration, on-line detector calibration and fine-tuning.
- Data Taking for $\varepsilon'/\varepsilon$ during September and October (42 days) at typically $2/3$ of beam nominal intensity, i.e. $1.0 \times 10^{12}$ $ppp$.
- About $1.09 \times 10^9$ events corresponding to 25 TBytes of data were recorded, containing about 650,000 CP-violating $K_L \rightarrow 2\pi^0$ decays, (the exact amount depending on the cuts used).This would give a $4 - 5 \times 10^{-4}$ statistical error on $\mathrm{Re}(\varepsilon'/\varepsilon)$ .
- Analysis is progressing, data is of good quality, systematic uncertainties are at very low level and mostly of statistical nature.

# Run 1998 - Detector Improvements

- ✔ LKr calorimeter repaired successfully; all HV blocking capacitors were replaced.
  All channels have been safely operated at 3 kV, in stable conditions.
- ✔ The Beam Pipe was replaced with a Carbon fiber one to reduce the high-multiplicity event rate due to showers in the B.P.
  The in-spill current in the 4 DCH went down by a factor of two.
- ✔ Mass-Box (online filter processor for charged decays) was upgraded to stand higher input rate.
- ✔ $50\%$ more beam intensity $\Rightarrow$ nominal beam intensity.
- ✔ Data-Handling hardware was upgraded to cope with the beam intensity .
  Event-building PC farm stands an incoming rate of up to 30 MB/s
  The Level-3/Data Recording/On-Line processing system (running on an 128-processor Meiko CS2) writes parallel output streams at a sustained rate of 13 MB/s

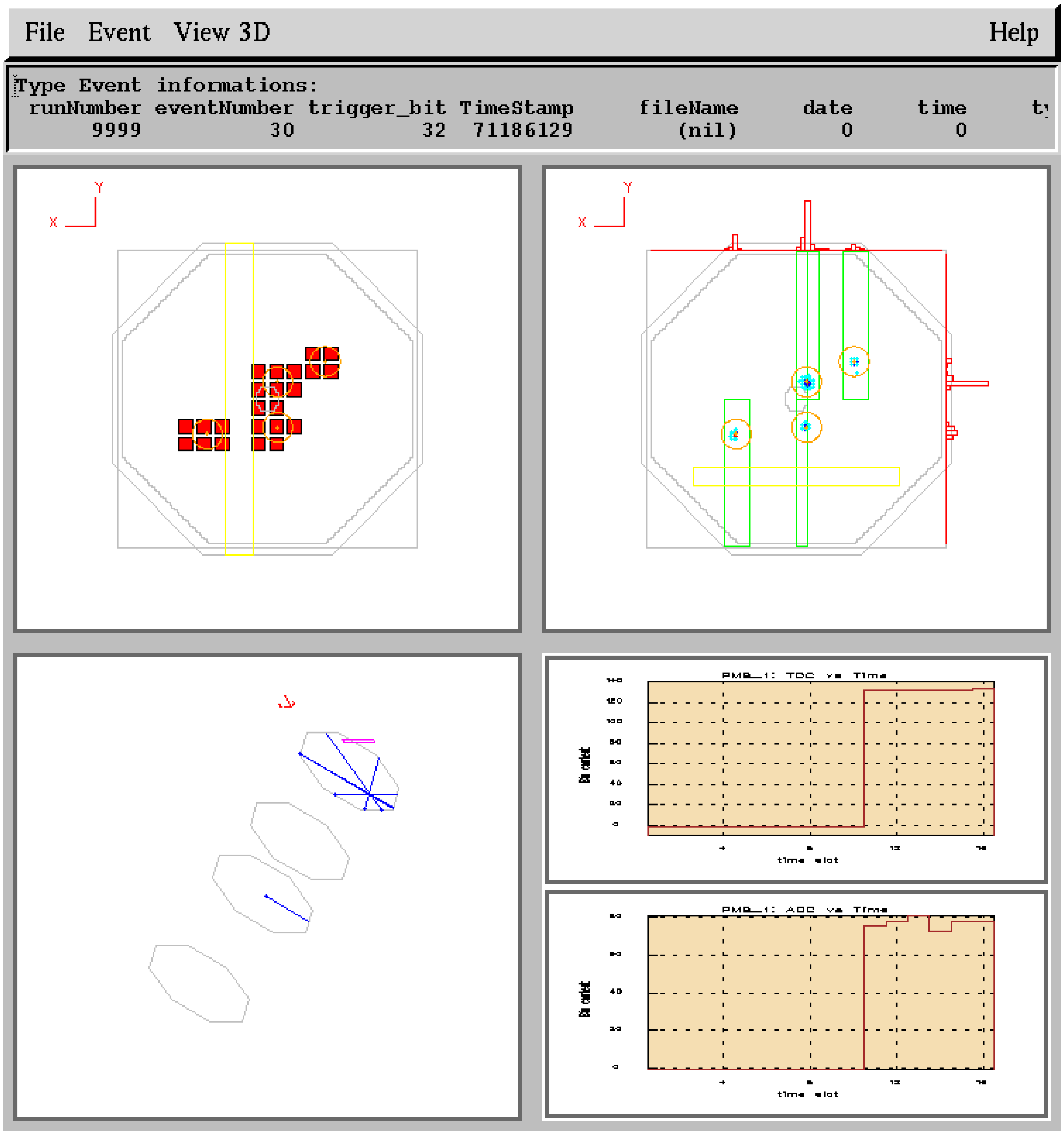
# Run 1998 - Statistics




$K_L \rightarrow \pi^0\pi^0$

- $0 < c\tau < 3.5\ c\tau_s$
- $70 < E_K < 170 GeV$

# On line display of a 2 $\pi^0$ decay



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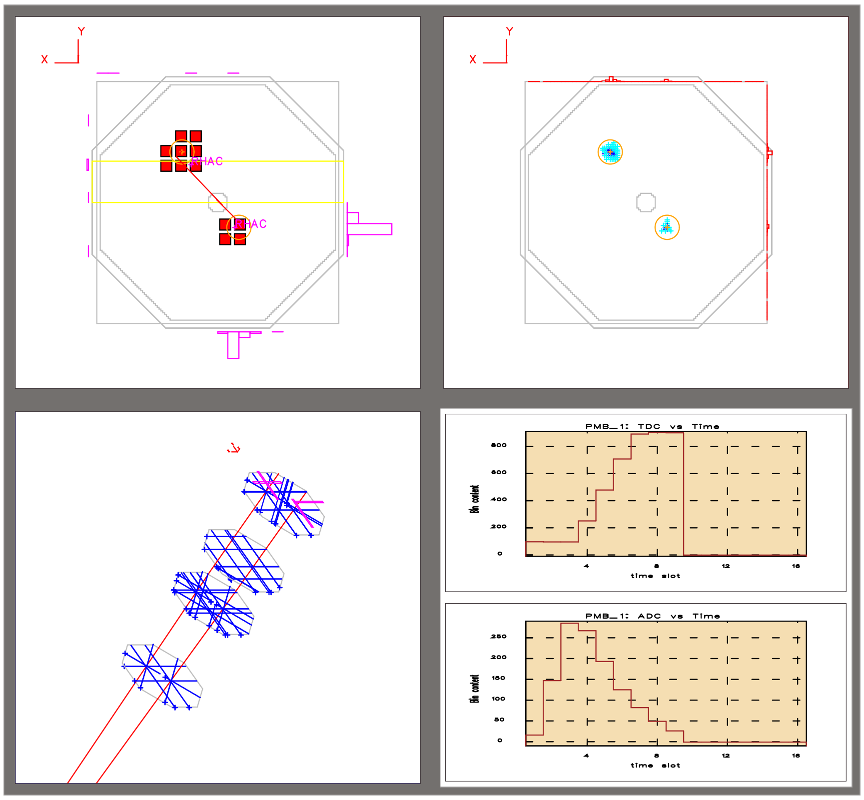
# On line display of a $\pi^+\pi^-$ decay



# Conclusions

- 1997 run was the first $\mathrm{Re}(\varepsilon'/\varepsilon)$ run of NA48, good success
- 1998 run has collected $>$ 2 million $K_L \to 2\pi^0$
- 120 days of running are forseen for 1999, with an option for running in 2000 too
- We are confident to reach the goal of $\delta(\mathrm{Re}(\varepsilon'/\varepsilon)\ ) \leq 2 \times 10^{-4}$