Status report on the Direct CP Violation Measurement with the NA48 experiment at 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

Menu

- The experiment
  - What are we looking for
  - The NA48 Method
  - The NA48 Beams
  - The NA48 Detectors
- Our First Re(ε'/ε) data taking: summer 1997
  - The run
  - Detector Performances
  - The Ongoing Analysis
    - K_S K_L separation : The tagging
    - Lifetime Weighting
    - Event selection and remaining backgrounds
  - Few corrections and Systematics
- 1998 Data Taking
  - Improvements and Achievements
- Prospects and conclusions

What are we looking for

CP Violation: Christenson, Cronin, Fitch and Turlay(1964)

Physical Particles	Allowed CP decays
$\mathrm{K_L} \approx K_{CP=-1} + \epsilon K_{CP=+1}$	$K_{CP=-1} \rightarrow$ 3body
$\mathrm{K_S} \approx K_{CP=+1} + \epsilon K_{CP=-1}$	$K_{CP=+1} \rightarrow$ 2 body

$$\boxed{\epsilon \approx 2 \cdot 10^{-3}\ (1964)}$$

Observed: $K_L \rightarrow \pi\pi$ from CP State Mixing (ϵ:INDIRECT)
Question: Is there any other $\mathrm{K_L} \rightarrow \pi\pi$???? ($\epsilon^{'}$:DIRECT)

❖Latest theoretical expectations predict $\mathrm{Re}(\varepsilon'/\varepsilon) \lesssim 10^{-3}$

The relative strength of Direct to Indirect CP Violation is extracted measuring the ratio R:

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

❖Previous generation experiments gave (ended in '93):

NA31 CERN	$(23.0 \pm 6.5) \cdot 10^{-4}$
E731 FermiLab	$(7.4 \pm 5.9) \cdot 10^{-4}$

❖New Generation of Experiments : KLOE, KTEV, NA48 designed to achieve a final precision of $\approx$ 1-2 10^{-4}

❖❖❖NEW: KTEV preliminary result: $(28.0 \pm 4.1) \cdot 10^{-4}$
in fair agreement with NA31 measurement

Comments on $\mathrm{Re}(\varepsilon'/\varepsilon)$ measurement Methods

In fixed target experiments , two different methods are (have been) used, to detect the four K_S ,K_L $\rightarrow 2\pi$ modes:

- Double beam technique (simultaneous K_S K_L beams). Two sub-classes:
  - One single final mode recorded at once (E731) (charged or neutral)
  - All four modes are detected concurrently (20% of E731 data, KTeV, NA48)
- Alternate K_S K_L data taking (NA31) :
  - Detect both modes with a single beam and then change beam.

There IS NOT a golden plated Method

Simultaneous Beams	**Alternate Beams**
$\rightarrow$ A priori important MC Corrections	Minimised MC corrections
$\rightarrow$ K_S K_L ambiguity	Clean beams
$\rightarrow$Beam and detector variations common to four modes$\Rrightarrow\approx$ cancel	Differential K_S K_L accidental activity, detector variations..

Comparison of experiments using different running modes $\Rrightarrow$ exciting, because of different systematics

The NA48 Method

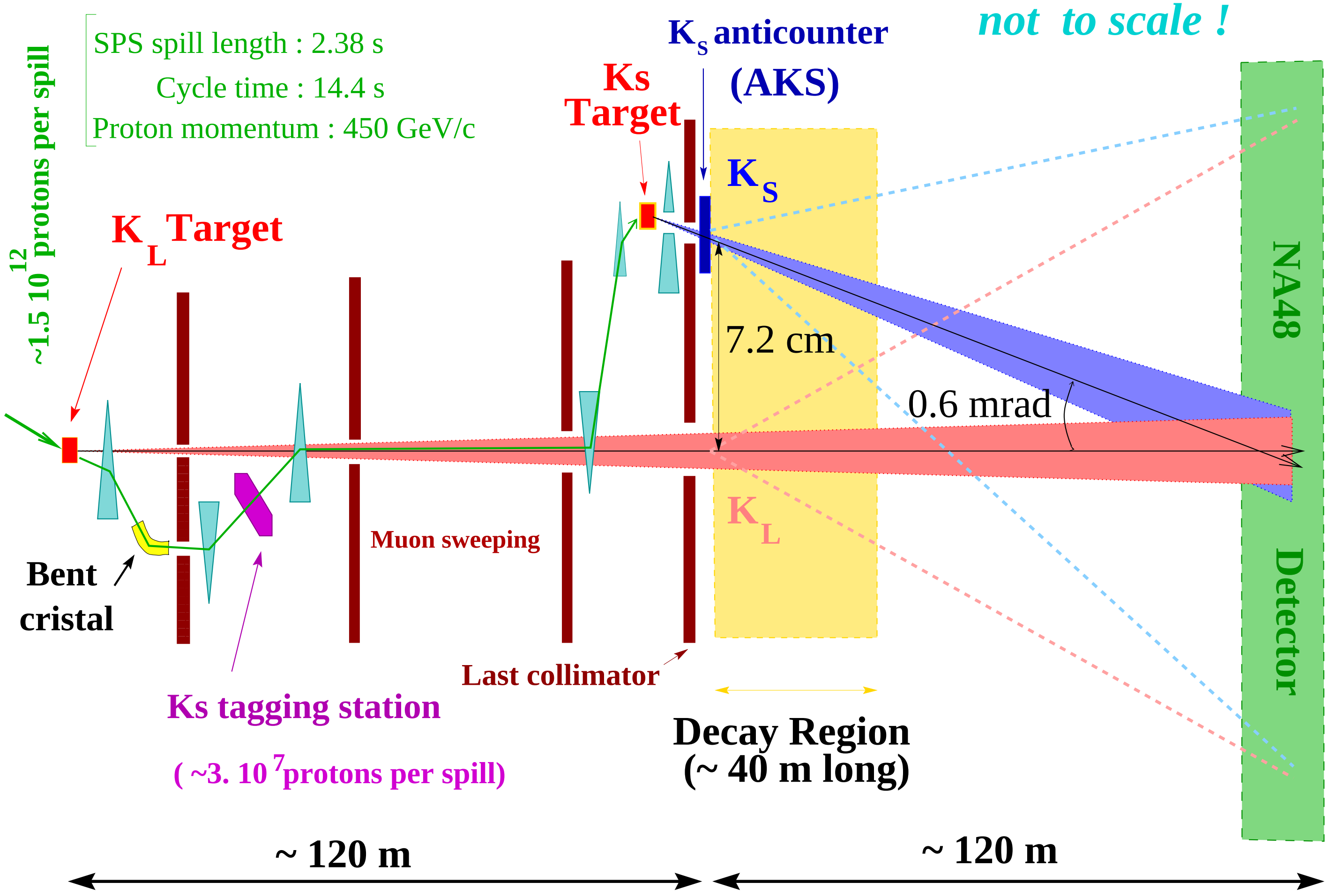
To minimize systematic effects related to detector (in)stabilities and (or) beam activity

- NA48 uses two simultaneous and almost collinear K_L and K_S beams
- NA48 collects concurrently the four decay modes in the same decay region
- NA48 identifies K_S decays tagging K_S protons upstream of the K_S target
- In order to minimize acceptance corrections NA48 applies a weighting procedure to get similar K_S and K_L decay spectra

To achieve the required statistical precision

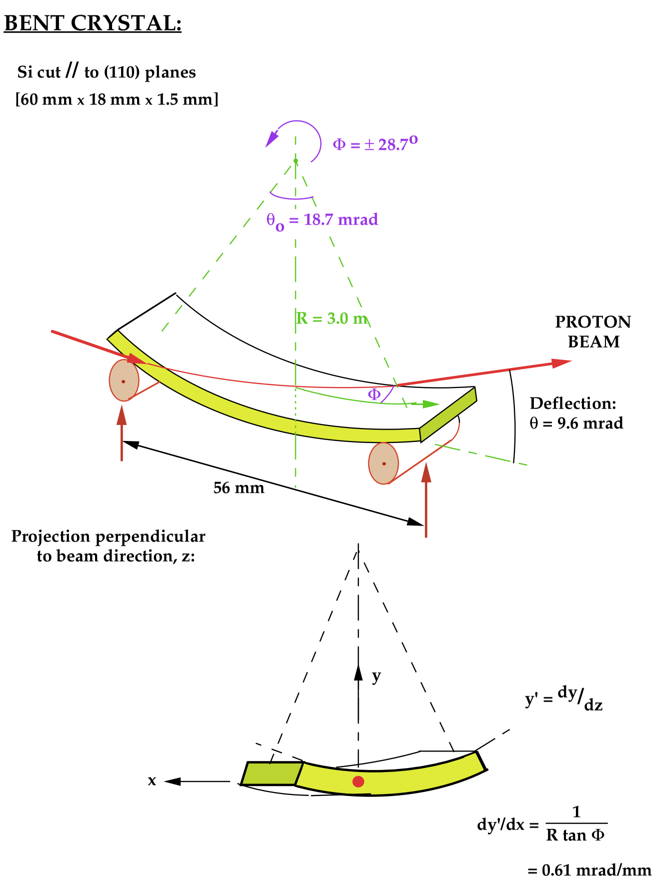
- NA48 uses intense proton beam
- NA48 has to collect 4-5 millions $K_L \to 2\pi^0$ which is the limiting mode, in 3-4 consecutive run periods
- Because of the long running period, NA48 needs a stable and efficient detector

Simultaneous K_S and K_L Beams



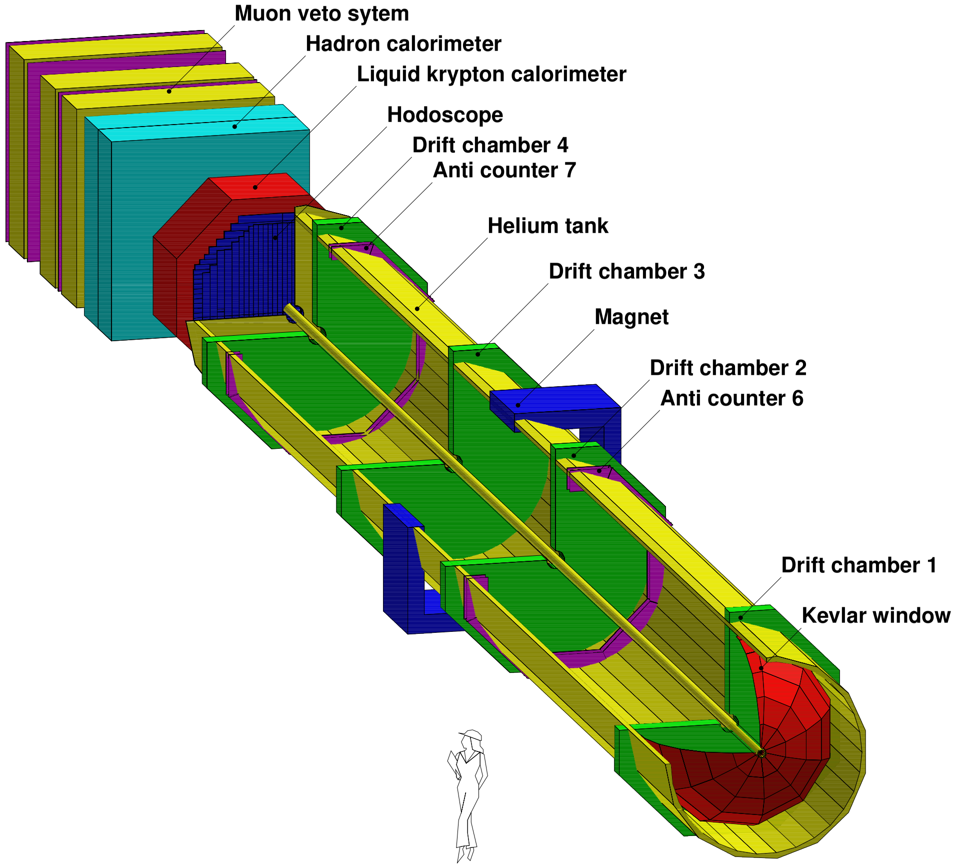
- K_S are distinguished from K_L by tagging the protons upstream of the K_S target
- NA48 detects all four modes concurrently and within the same fiducial region

The bending bent crystal



- Silicon mono-crystal
- The coherent scattering on the crystal lattice nuclei, forces the beam to follow lattice direction (channeling)
- Advantages of the crystal use
  - Deflects cleanly the proton beam in a very short length: equivalent bending power 14.4Tm
  - It doesn't cancel the muon deflecting action of the upstream magnet
  - Acts as a beam splitter selecting the desired small fraction $\approx 5 \cdot 10^{-5}$ of the incoming proton beam
  - Garanties a sharply defined emittance of the outgoing beam in both horizontal and vertical planes

The NA48 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 $\mathrm{K_L} \to \pi^+\pi^-$
- All detectors offer redundant fine time information ($\sigma \leq$1ns)

Our first $\mathrm{Re}(\varepsilon'/\varepsilon)$ data taking: summer 1997

- Installation and commissioning of the readout and neutral trigger electronics of the Liquid Krypton calorimeter

- DAQ and triggering systems integration, online detector calibration and fine-tuning

- Fire in the SPS!!!! Took 6 weeks for a special task force to clean-up the SPS area.

- First Physics run: Sep/Oct 1997 with 2/3 nominal intensity beam (10^{12}ppp)

- 42 days of data taking
  - Readout rate 80Mbytes/s
  - 12000 events/spill sent to the Central Data Recording through optical link
  - Transfer rate to CDR 12Mbytes/s
  - 25 Tbytes of raw data written on tape

- This run gave us $\approx$650000 $\mathrm{K_L} \rightarrow \pi^0\pi^0$ within the fiducial cuts (energy 70GeV $< E_K <$ 170 GeV and lifetime $0 < \tau < 4\tau_S$.

- Expect a statistical error of 4-5 10^{-4} on $\mathrm{Re}(\varepsilon'/\varepsilon)$ (after weighting).

Rates and Triggers

Decay rates in the fiducial region are dominated by K_L beam : 10^6 kaons per spill decay between collimators and detector $\Rrightarrow$ Input trigger rates $\approx$ 400KHz.

The $\pi^+\pi^-$ Trigger in 97

- Level 1: Charged Hodoscope coincidence and Total energy in calorimeters
- Level 2: Fast tracking in the spectrometer. A farm of processors reconstruct vertex and mass
  - Output L2 rate = .8KHz , Dead Time $\approx$ 1%
  - Combined L1*L2 efficiency:

    K_S : (90.61±0.08)% ,K_L : (90.66±0.10)%

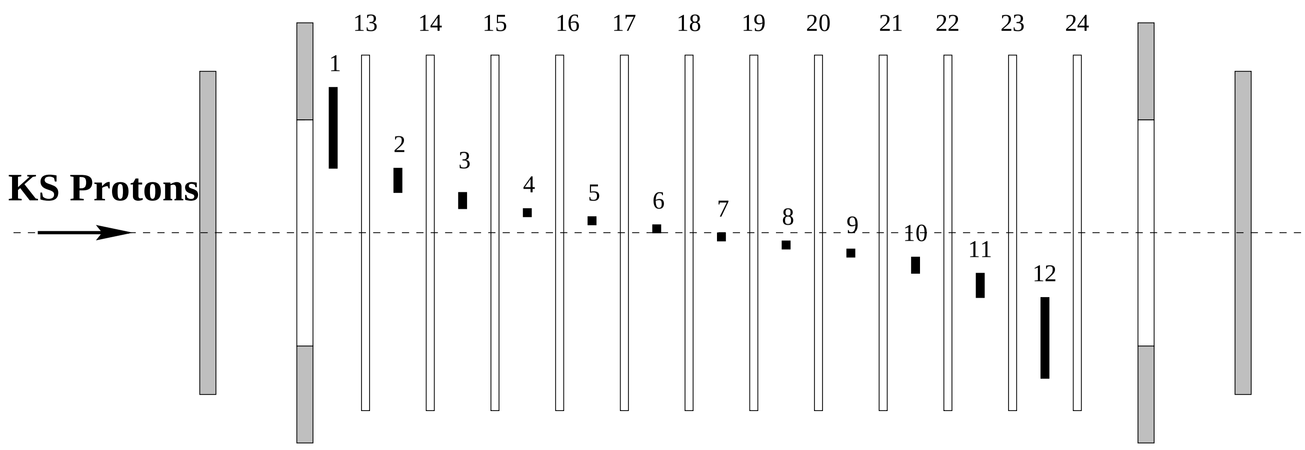
The $\pi^0\pi^0$ Trigger in 97

- Fully pipelined trigger, deadtimeless
- 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 and Center of Gravity
  - Output rate =2KHz
  - Efficiency:

    K_S : (99.85±0.05)%,K_L :(99.90±0.06)%

The Tagger: I

Tagger from side view



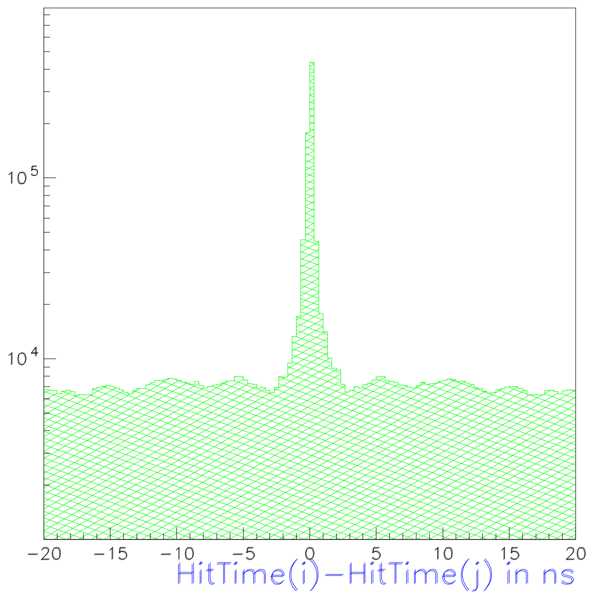
: Vertical Counters : Horizontal Counters

The tagger: two ladders, one Horizontal and one Vertical, each one made of 12 scintillating counters sharing the K_S proton beam.

- At least 2 hits per proton crossing (one in the vertical and one in the horizontal ladder).
- Counter width: Variable (200-3000μm), following the beam profile, to equalize the individual Counter rates (1-2MHz)
- 8-bit 1GHz FADC readout
- Performances:
  - Single counter resolution: $\approx$ 140ps
  - Close pulses resolution: down to 4-5 ns

The Tagger: II

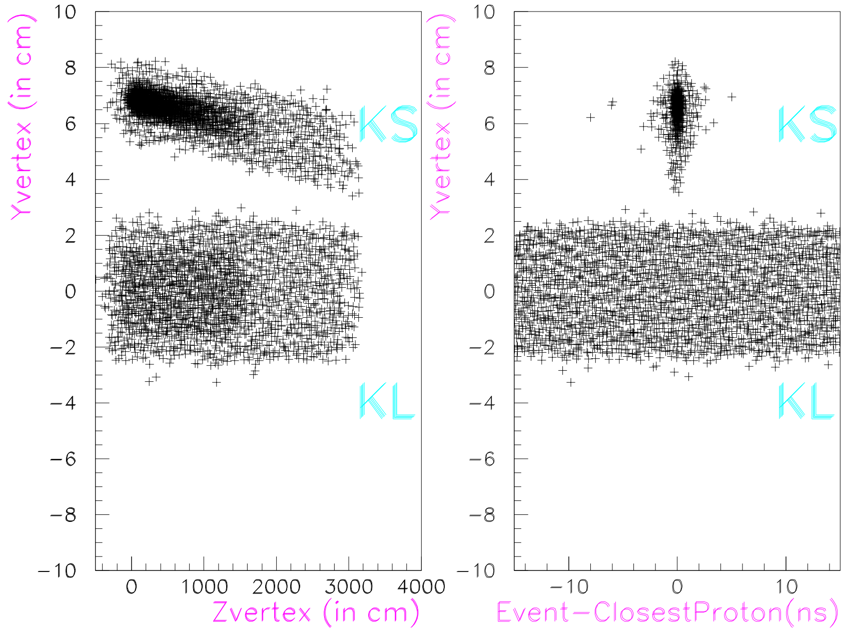
- Tagger: allows as well the observation of beam structures (200MHz: RF of the SPS)



Tagging example : Charged Events

Beam known from Vertex Reconstruction

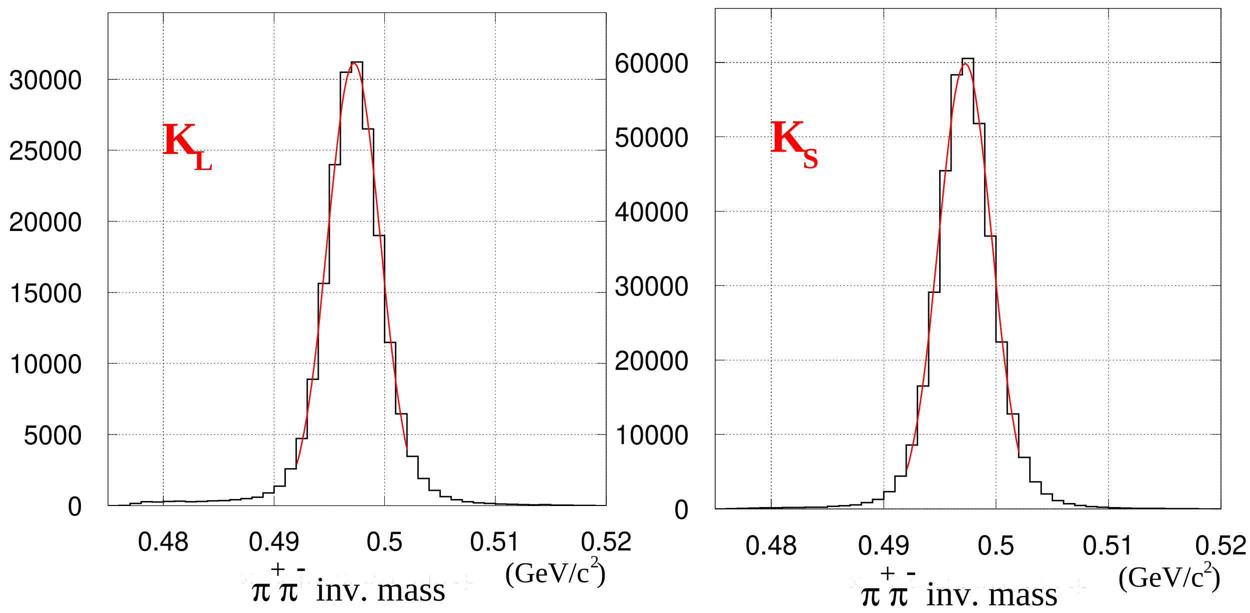
ChHodoscope Time-Tagger Coincidences



Charged Mode $K_{L,S} \to \pi^+\pi^-$

Spectrometer performance

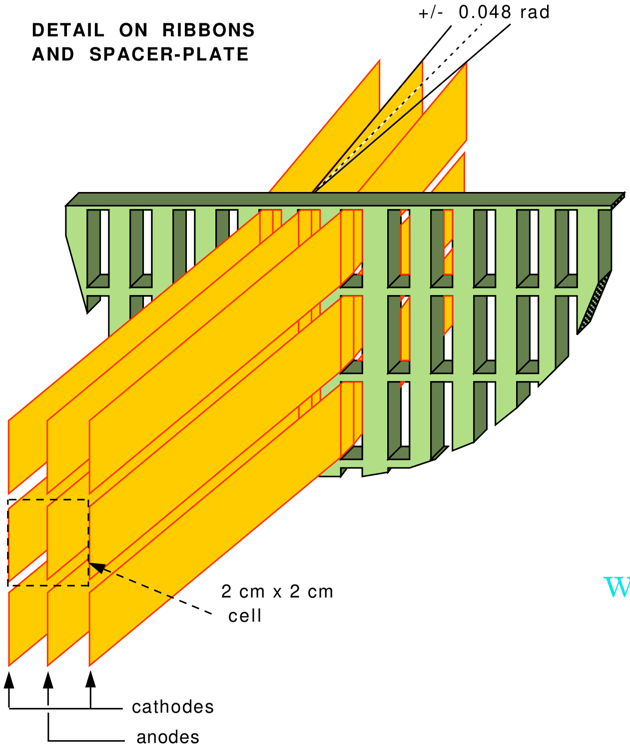
- Vertex resolution: $\approx$2mm in X and Y
- Mass resolution: ~ 2.5 MeV/c^2
- $\frac{\sigma(P)}{P} = 0.48\,\% \oplus 0.009\ P[\mathrm{GeV/c}]\,\%$
  (from e^- scan at 25 and 100 GeV)
- Time resolution per event: ≈ 0.7ns



Charged Event Time

- Given by the Charged Hodoscope with a precision better than 200ps
- Spectrometer event time can be used for cross-checks

The LKR calorimeter



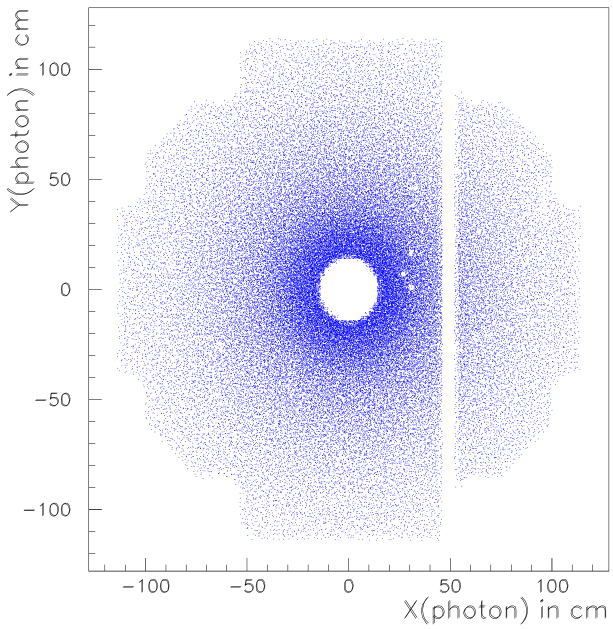
- Made of $\approx 9m^3$ LKr and Cu-Be-Co electrodes
- 1 Cell: 2cm×2cm×127cm
- Five Spacer plates
- Electrodes: ± 48mrad zig-zag in each spacer
- The 2cm gap is controled

with a precision $\approx \pm 100\mu$m

Neutral Mode $K_{L,S} \to \pi^0\pi^0$

LKr calorimeter operation

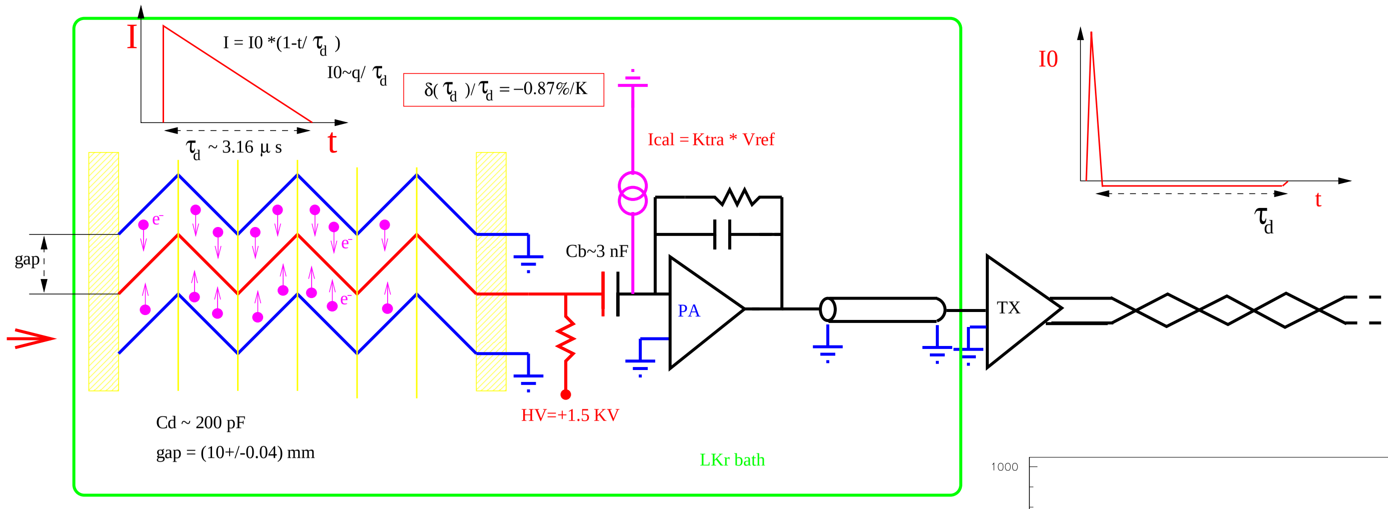
- Operation at reduced HV (1.5 kV) due to few leaking capacitors
  - $\approx$ 20% more electronic noise
  - a small $<$ 0.5% energy correction for space charge
- One column (4 cm wide) not connected to HV(15% acceptance loss for good $K_L \to 2\pi^0$)
- 40 dead channels (0.3% of channels)

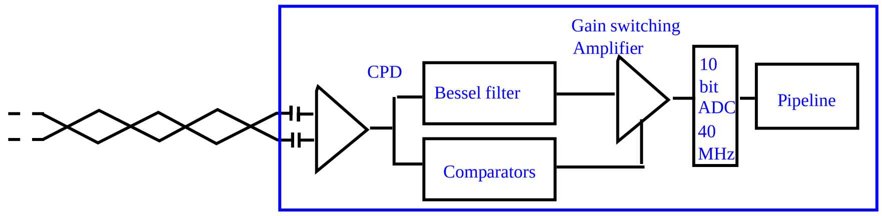


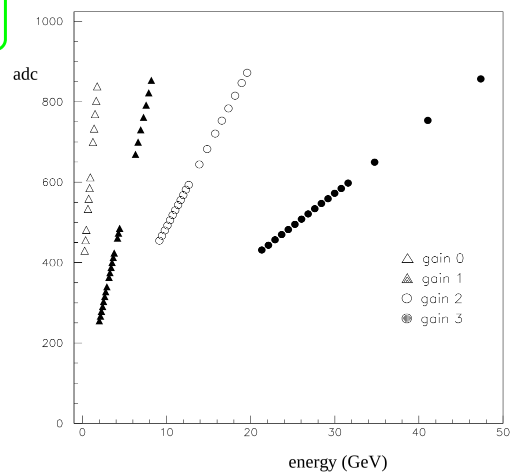
Performances

- $\approx$1mm position resolution in both X and Y
- 1.1MeV π^0 mass resolution
- Intrinsic time resolution per event $\approx$200ps $\Rrightarrow$ LKR gives the Neutral Event Time
- Neutral Hodoscope offers redundant time information for checking

LKR readout and calibration



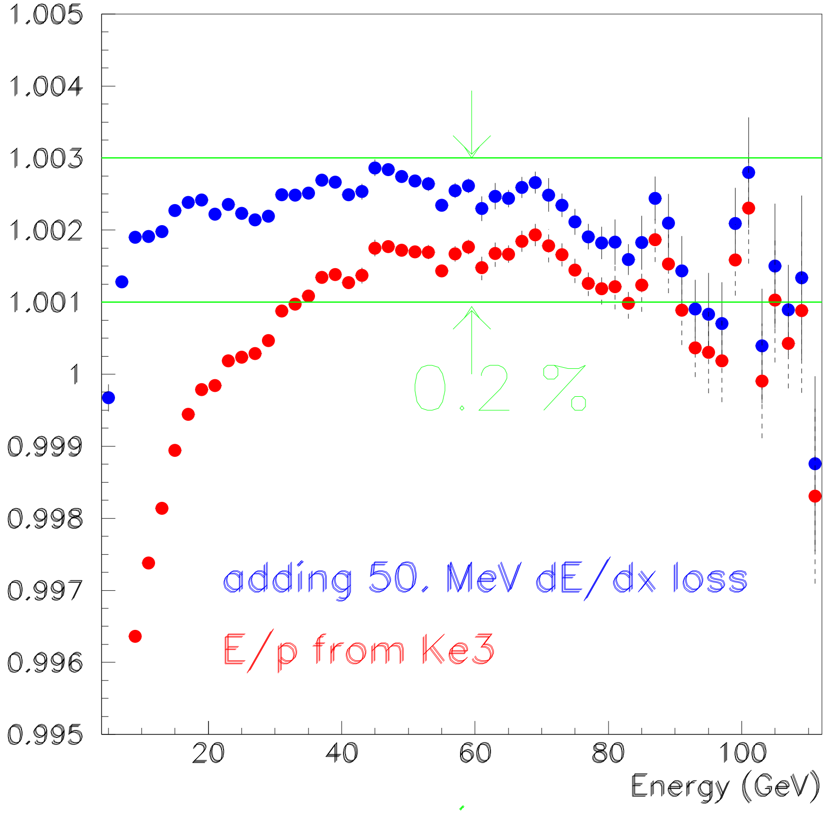


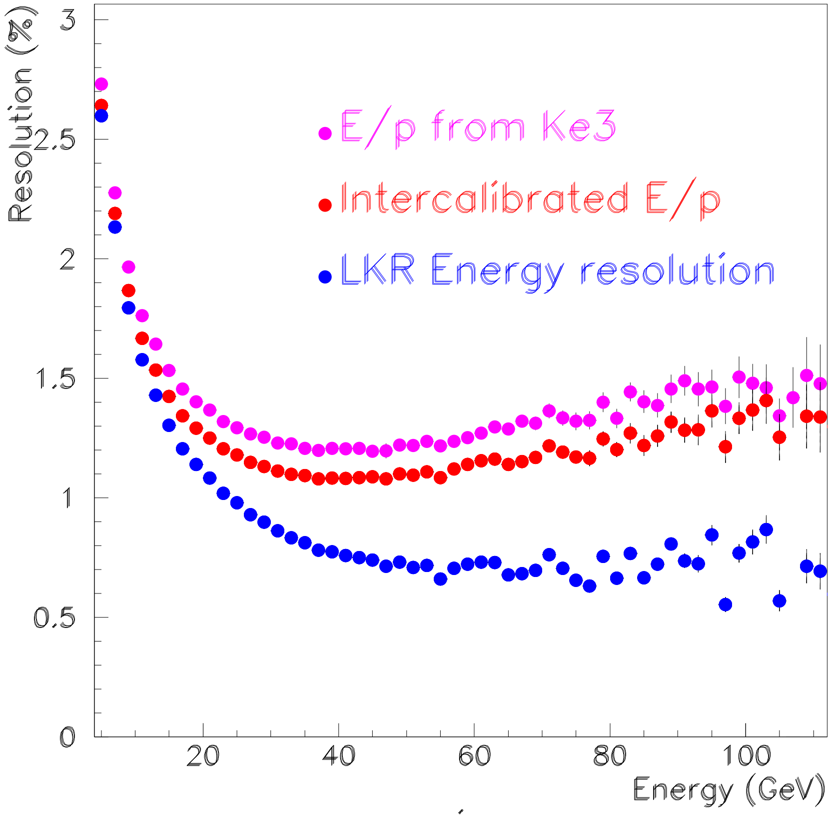


- In cold: Signal pre-amplification
- On feedthroughs: Speed-up and differentiate the signal
- CPDs: Shaping, 4 Gains $\times$ 10 ADC bits dynamic range (mesuring from $\approx$3.5MeV to $\approx$50GeV per cell), Asynchronous 40MHz sampling

- Regular calibrations during data taking to follow offset and gain stability
- Stability with time $\approx$ 0.1%
- T0s calculated using Physics events (photons)

Linearity and Resolution :E/P with electrons from K_{e3}



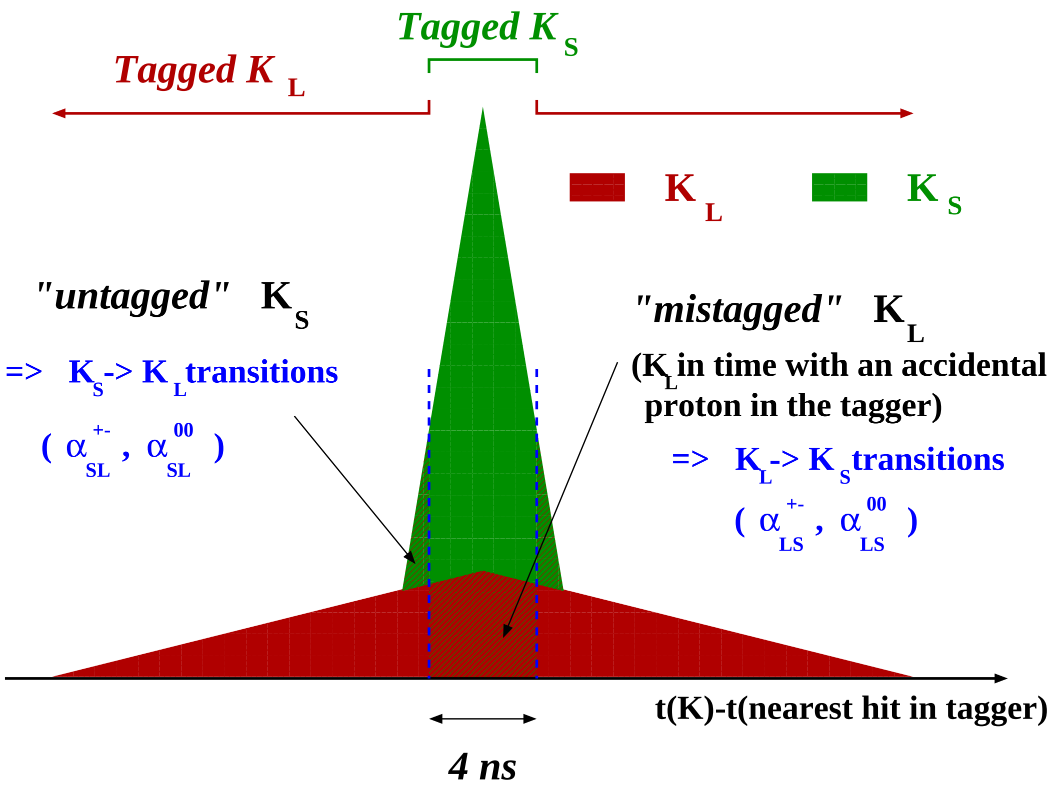


- 5 $\rightarrow$ 100 GeV : linear within$\sim$ 0.2 %
- Cell-to-Cell energy uniformity shown a 0.43% dispersion
- After E/P intercalibration and Spectrometer term subtraction:

  $\frac{\sigma(E)}{E} = \frac{3.5\%}{\sqrt{E}} \oplus \frac{110MeV}{E} \oplus 0.6\%$ for a 11×11 showerbox

The ongoing analysis ⇒ Tagging : In general

Sketch of the principle

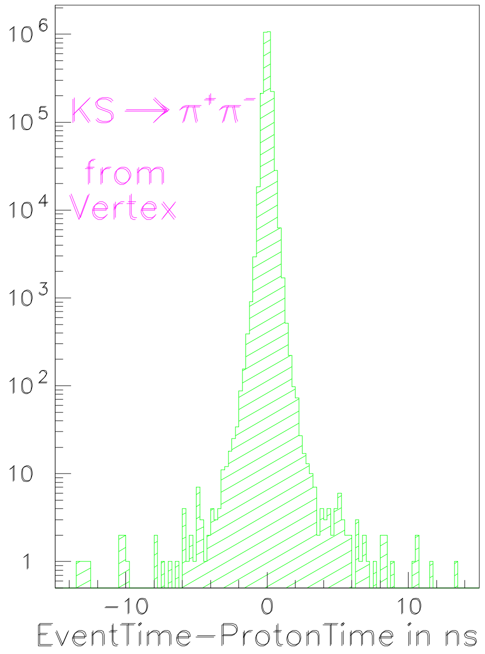


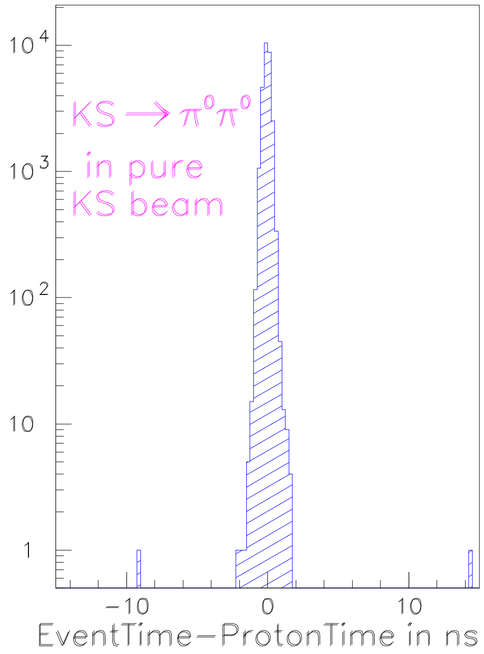
- $\mathrm{K_S}$: $|\Delta T|$ <2ns, $\mathrm{K_L}$: $|\Delta T|$ >2ns
- $\mathrm{K_L} \rightarrow \mathrm{K_S}$ transitions (α_{LS}): proportional to the rate seen by the tagger
  - Symmetric charged-neutral in first order
  - R sensitivity to $(\alpha^{+-}_{LS} - \alpha^{00}_{LS})$: $\Delta(R) \approx 1.7(\alpha^{+-}_{LS} - \alpha^{00}_{LS})$
- $\mathrm{K_S} \rightarrow \mathrm{K_L}$ transitions (α_{SL}): due to time reconstruction inefficiencies (tails)
  - A priori different between charged and neutral
  - R sensitivity to $(\alpha^{+-}_{SL} - \alpha^{00}_{SL})$: $\Delta(R) \approx 5.3(\alpha^{+-}_{SL} - \alpha^{00}_{SL})$

Ongoing analysis⇛Tagging:Measurements I

α_{SL}^{+-} and α_{SL}^{00}: Tagging inefficiency or

what does tagger answer to true KS decays?





✦ Charged Mode : Use true K_S (from vertex) and count events outside the tagging window : ⇛

$$\boxed{\alpha_{SL}{}^{+-} \sim (1.4 \pm 0.1) \times 10^{-4}}$$

!! Using redundant time information: 2/3 of the inefficiency is due to the tagger ⇛ charged neutral democratic

✦ Neutral Mode : Three methods for tagging control:

- ✦ Pure K_S runs. Gives α_{SL}^{00}
- ✦ $K_S \rightarrow \pi^0 e^+ e^- \gamma$ through the run. Gives α_{SL}^{00}
- ✦ Compare Charged and Neutral event Times in neutral K_L +K_S decays with conversions. Gives $\alpha_{SL}^{+-} - \alpha_{SL}^{00}$

$$\boxed{\alpha_{SL}^{+-} - \alpha_{SL}^{00} \text{ known to } \leq 1 \cdot 10^{-4}}$$

Ongoing analysis⇛Tagging:Measurements II

α_{LS}^{+-} and α_{LS}^{00}: Dilution or

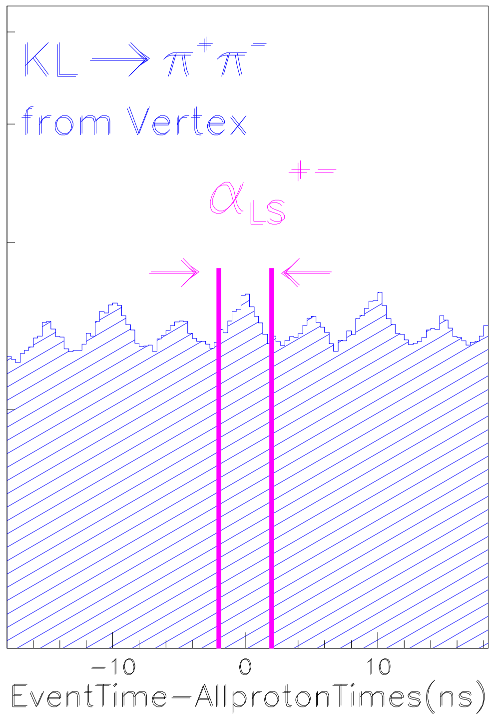
how many K_L are misidentified as K_S ?

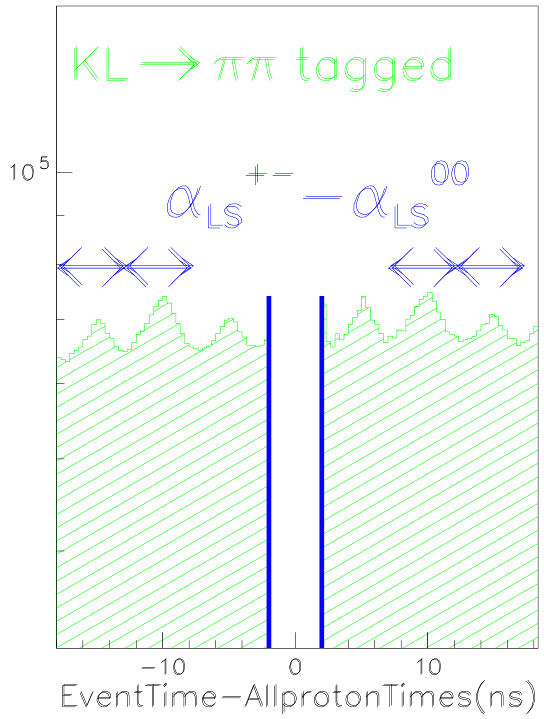
- METHOD:
- From true $K_L \to \pi^+\pi^-$ events, we compute :

$$\alpha_{LS}^{+-} = (11.20 \pm 0.03)\%$$

- From K_L tagged charged and neutral ($|\Delta T| > 2ns$) we compute $\alpha_{LS}^{+-} - \alpha_{LS}^{00}$ in side bands ± 2ns wide

$$\alpha_{LS}^{00} - \alpha_{LS}^{+-} = (0.11 \pm 0.05)\%$$



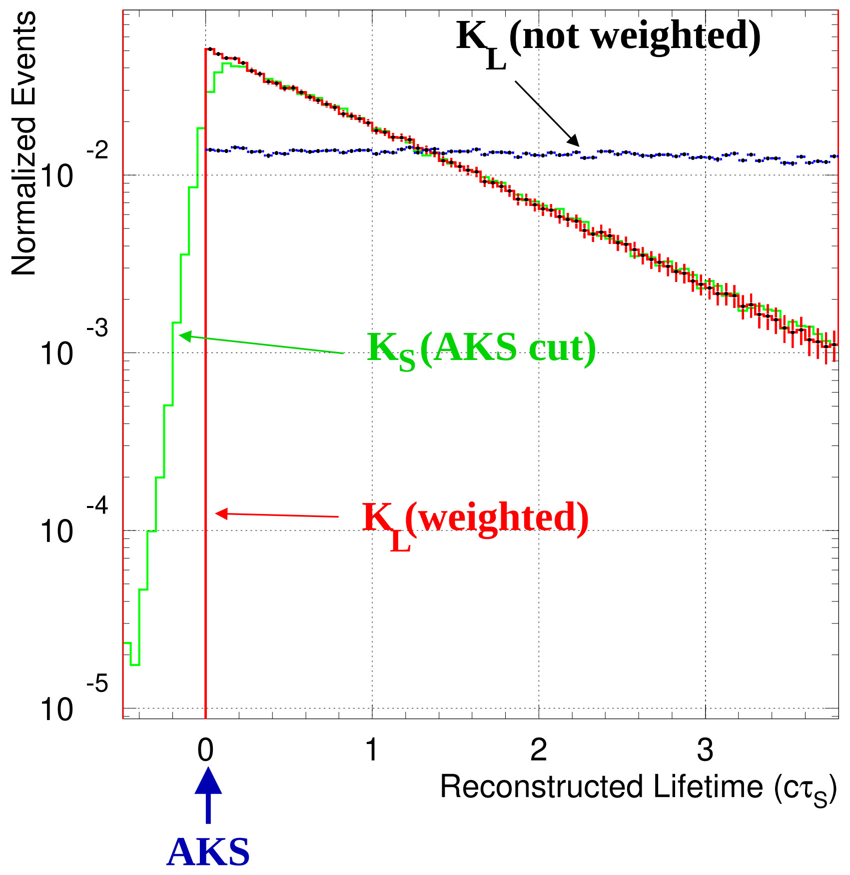


- Total tagging uncertainty on $\mathrm{Re}(\varepsilon'/\varepsilon)$ (inefficiency+ dilution) is statistically limited :

$$\boxed{\leq 2 \cdot 10^{-4}}$$

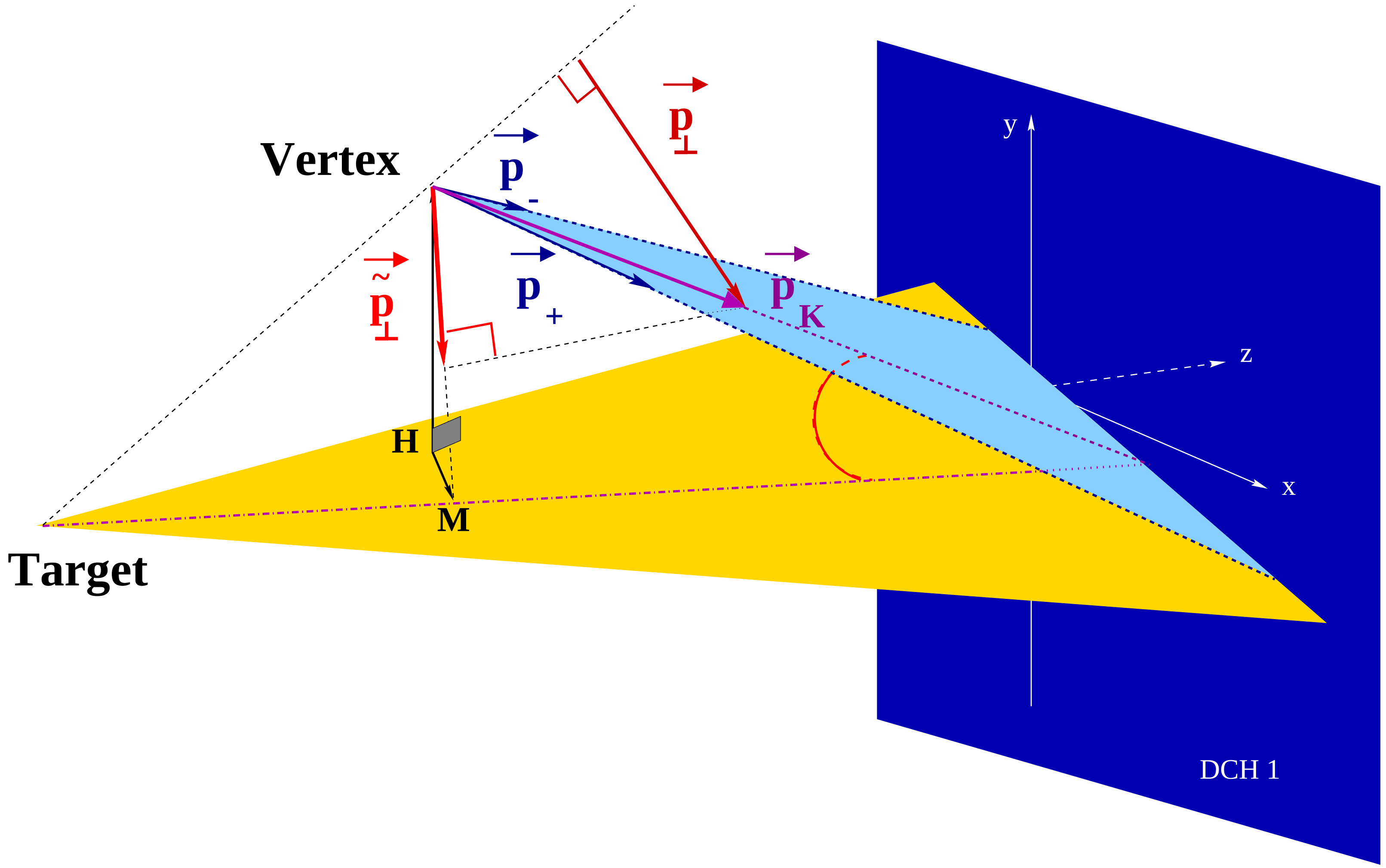
The ongoing analysis $\Rightarrow$ Lifetime weighting

- Weighting $\Rightarrow$ make similar K_S K_L lifetime distributions
- Without weighting , because of the spectra difference, the energy dependance of the acceptance correction would be large ($\approx 13\%$)
- Weighting reduces acceptance corrections to less than 0.5 %
- Weighting cost : increase of the statistical error (up to 40 % with $c\tau < 4c\tau_S$)



- Unweighted analysis can be performed as a check

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

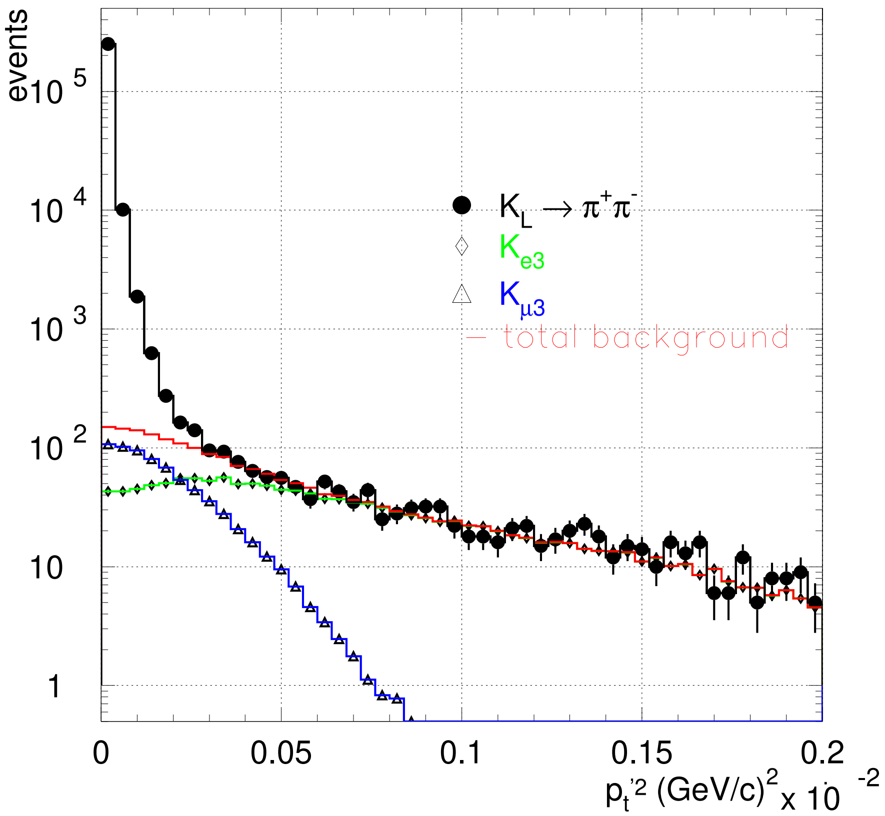


Because of the different target positions, $P_\perp{}^2$ is very different for K_S and K_L .

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

The ongoing analysis ⇛ Charged Background

- Mainly Kμ3 and Ke3 (100 times more than $K_L \rightarrow \pi^+\pi^-$ decays)
- First Rejection at the Trigger Level
- In the analysis:
  - Electron rejection using E/P
  - Muon rejection using the muon Veto
- The remaining background: studied in the plane mass vs $P_\perp{}^2$ where $P_\perp{}^2$ is K_S K_L invariant
  - Using identified samples of K_{e3} and $K_{\mu3}$
  - Is measured in selected control regions
  - Is finally extrapolated to the signal region

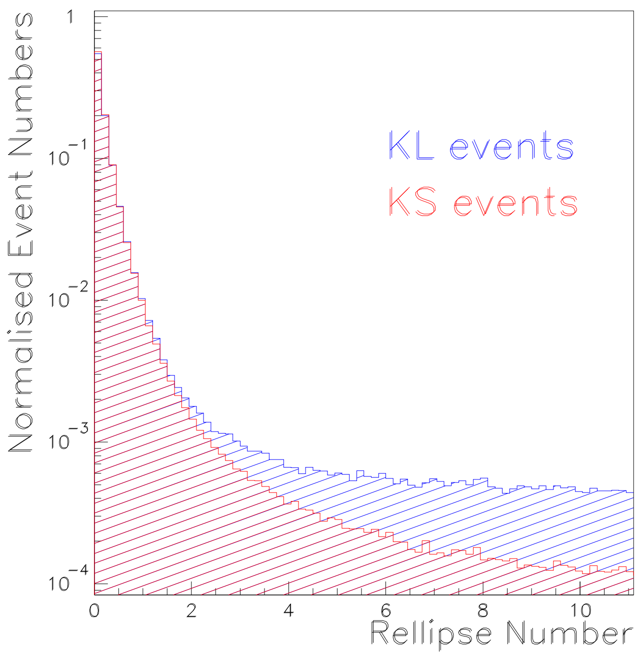


Charged background under the signal: $\lesssim 0.3\%$

The ongoing analysis $\Rrightarrow$ Neutral Background

- $K_L \to 3\pi^0 \approx 210 \times K_L \to 2\pi^0$
- First rejection at the trigger level
- $K_L \to 2\pi^0 \to 4\gamma$ reconstruction:
  - Vertex position is calculated fixing Kaon Invariant Mass
  - Using Vertex Position$\Rrightarrow$ find the best π^0 combination
  - $K_L \to 3\pi^0 \to 4\gamma$ (+ 2 γ missing) have less detected energy
    - $\Rrightarrow$ Reconstructed Vertex pushed towards the calorimeter
    - $\Rrightarrow$ Large reconstructed lifetime
    - $\Rrightarrow$ non-resonant mass combinations
- Use the R_{ell} estimator:

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



Signal region :

$$\boxed{R_{ell} < 1.5}$$

$3\pi^0$ Background level :

- not weighted$\sim 3.10^{-3}$
- weighted $\lesssim 1.10^{-3}$

Corrections and Systematic checks

Corrections

- AKS correction: slight acceptance difference between charged and neutral (from geometry, $\approx 0.3\%$ on R)
- Differential K_S -K_L losses due to accidental activity: calculated overlaying events with randoms (small)
- Monte Carlo Correction: taking into account slight K_S K_L beam differences and scattering in the AKS (total correction $< 0.5\%$ on R)
- ....

Systematic checks

- Neutral energy scale
  - Neutral energy scale must be known to $\approx$few 10^{-4} to not bias the double ratio

$$\text{Distance} \propto \sqrt{\sum_{i=1,j>i}^{4} E_i \cdot E_j \times \left[(x_i - x_j)^2 + (y_i - y_j)^2\right]} / M_K$$

  - The energy scale is adjusted by fitting the AKS position which sharply defines the beginning of the K_S decay region (stable within $\approx \pm 5.10^{-4}$)
  - Special runs (with π^- beam and thin target) are used to cross-check energy scale and related systematic effects
- Stability with time (i.e. running conditions)
- Stability within the burst
- Stability with beam intensity variations
- ....

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

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

$\Rightarrow$ sustained transfer rate of 20 Mbytes/s

$\Rightarrow$ ~ 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

Conclusions

- ε'/ε analysis on 97 data is well advanced

- Particular care to systematic studies concerning the stability of the result

- In 98, ≈ 3 times more data have been recorded , analysis is starting. The higher statistics will allow better constraints on systematics

- Data taking for ε'/ε will continue in 1999 and 2000 (~ 120 days/year) to achieve a precision of 2×10^{-4}