A New Measurement of Direct CP Violation by NA48

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on behalf of the NA48 COLLABORATION

Cagliari, Cambridge, CERN, Dubna, Edinburgh,
Ferrara, Firenze, Mainz, Orsay, Perugia, Pisa,
Saclay, Siegen, Torino, Warsaw, Wien

Outline

1. Direct CP violation in K^0 system and ϵ'/ϵ

2. How to measure ϵ'/ϵ ? NA48 method and setup

3. Data analysis
   - analysis overview
   - highlights of some key features
   - result

Conclusions

1. Direct CP violation and ϵ'/ϵ

CP violation in neutral kaon system is dominated by states mixing:

Mass eigenstates (K_S and K_L) are not pure CP eigenstates (K_1 and K_2)

$$K_S = K_1 + \epsilon\ K_2$$
$$K_L = K_2 + \epsilon\ K_1$$

indirect CP violation: $|\epsilon| = (2.28 \pm 0.02)\ 10^{-3}$

Is there also a component of *direct* CP violation in the decay process itself ?

$$|A(K^0 \to F)| \neq |A(\overline{K^0} \to \overline{F})|$$

Need interference of two decay amplitudes
(with different strong phases)

Direct CP Violation

$\pi\pi$ from K^0 can have I=0 or 2 $\Rightarrow$ 2 amplitudes A_0 and A_2

Define ratio of CP violating/CP conserving amplitudes :

$$\begin{array}{rcccl} \frac{A(K_L\to\pi^+\pi^-)}{A(K_S\to\pi^+\pi^-)} & \equiv & \eta_{+-} & = & \epsilon+\epsilon' \\ \frac{A(K_L\to\pi^0\pi^0)}{A(K_S\to\pi^0\pi^0)} & \equiv & \eta_{00} & = & \epsilon-2\epsilon' \end{array}$$

ϵ' : direct CP violation parameter

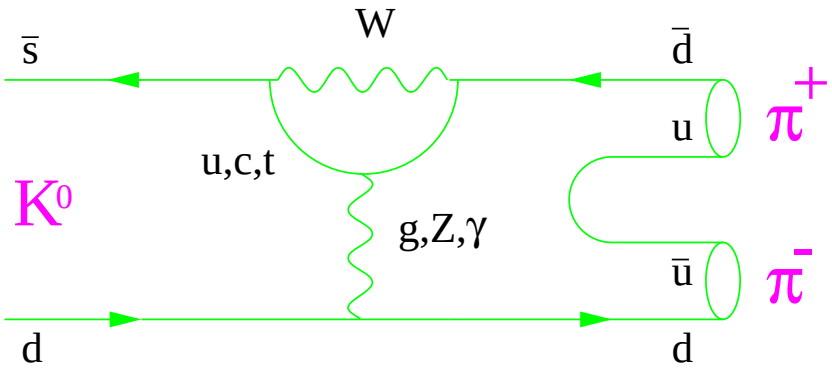
$\epsilon' \approx \frac{i}{\sqrt{2}} Im(\frac{\mathcal{A}_2}{\mathcal{A}_0}) e^{i(\delta_2-\delta_0)}$

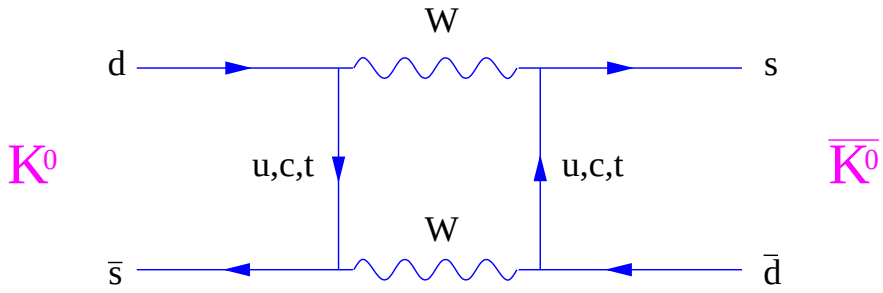
Experimental observable :

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

Standard Model predictions

Indirect violation
through mixing
$K^0/\overline{K^0}$ oscillations
$\Rightarrow \varepsilon$ parameter





Direct violation
through decay
penguin diagrams
$\Rightarrow \varepsilon'$ parameter

Typical theoretical predictions :

$\epsilon'/\epsilon \approx$ few 10^{-4} to $\approx 2.10^{-3}$

Improvements from forthcoming lattice QCD computations (?)

Current experimental situation of ϵ'/ϵ

Previous generation of experiments (results in early 90's) :

- NA31: $(23.0 \pm 6.5).10^{-4}$
- E731: $(7.4 \pm 5.9).10^{-4}$

$\epsilon'/\epsilon \neq 0$? $\Rightarrow$ New generation of experiments

First published results two years ago :

- KTeV: $(28.0 \pm 4.1).10^{-4}$ (20% of 96-97 stat)
- NA48: $(18.5 \pm 7.3).10^{-4}$ (97 data)

Preliminary NA48 result on 98 data last year :

- NA48: $(14.0 \pm 4.3).10^{-4}$ (combined with 97)

Direct CP violation established

World average: $(19.2 \pm 2.5).10^{-4}$ BUT $\chi^2/\text{ndf} = 10.4/3$
Need final results from NA48 and KTeV to clarify situation

TODAY : NA48 result based on 98+99 data
($\approx$ 7 times the 97 published statistics)

2. NA48 method and setup

Double ratio measurement:

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

$\Leftrightarrow$ Count number of events

Need $> 3.10^6$ $\mathrm{K_L} \to \pi^0\pi^0$ for stat error on R $< 0.1\%$

Measure R $\Rightarrow$ exploit cancellation of possible systematics

Principles to minimise systematic effects :

- The 4 modes are taken simultaneously from the same decay region

$\Rightarrow$ Cancellation of fluxes, dead times, inefficiencies, accidental losses...

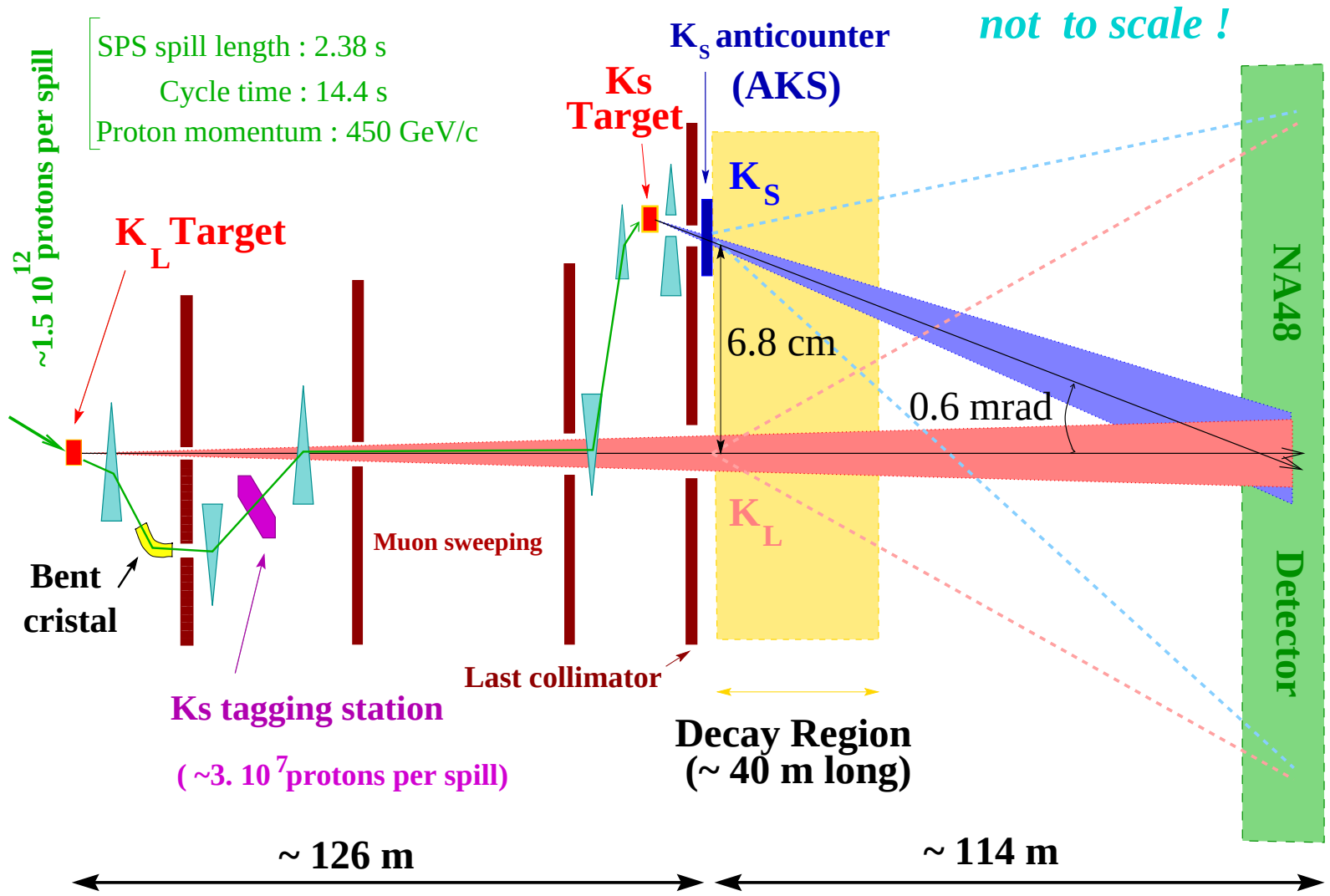
- Apply lifetime weighting to equalise distribution of $\mathrm{K_S}$ and $\mathrm{K_L}$ decay positions

$\Rightarrow$ Cancellation of detector acceptance effects

- Use quasihomogeneous Liquid Krypton calorimeter to detect $\pi^0\pi^0$ and magnetic spectrometer for $\pi^+\pi^-$

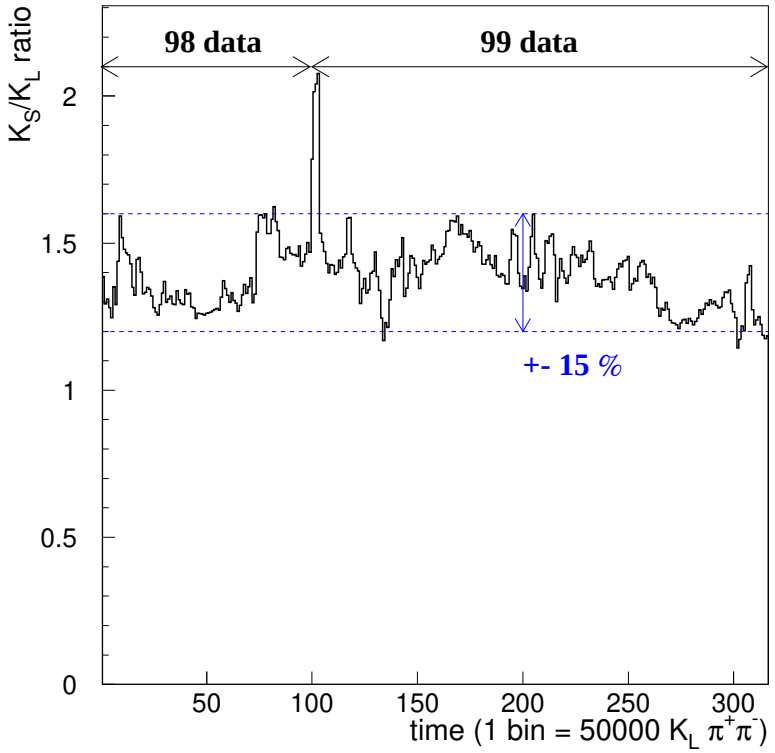
$\Rightarrow$ Minimise backgrounds

NA48 simultaneous and collinear K_S and K_L beams



K_S and K_L beams are distinguished by proton tagging upstream of the K_S target.

How simultaneous are K_S and K_L ?



Variation in K_S/K_L ratio with beam conditions (RMS $\approx 9\%$)

To remove any sensitivity to detector variations :

reweight K_S events to equalise K_S/K_L ratio

In practice, small effect on R ($\approx 3 \cdot 10^{-4}$)

Decay region definition

- $0 \leq \tau \leq 3.5$

  τ = proper time along the beam axis, in K_S lifetime units

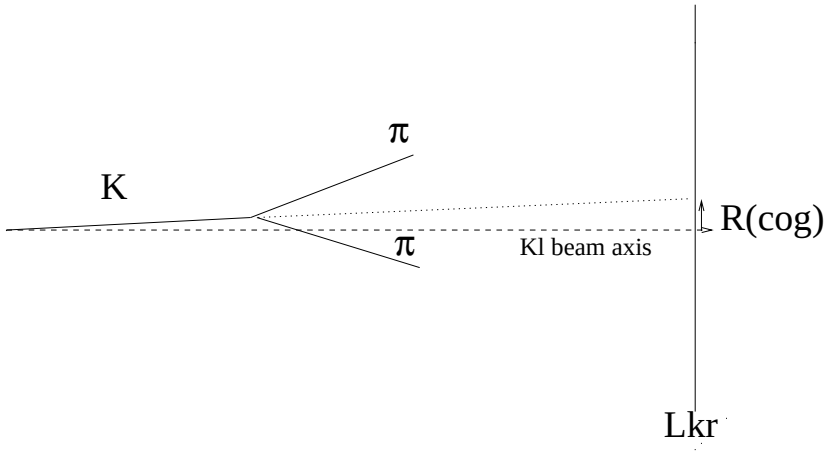
  $\tau = (z_{vertex} - z_0)\frac{M_K}{E_K}\frac{1}{c\tau_{K_S}}$

  For K_S beginning of decay region is defined by AKS anticounter

- $70 \leq E_K \leq 170$ GeV (K_L/K_S variations $< 20\%$)

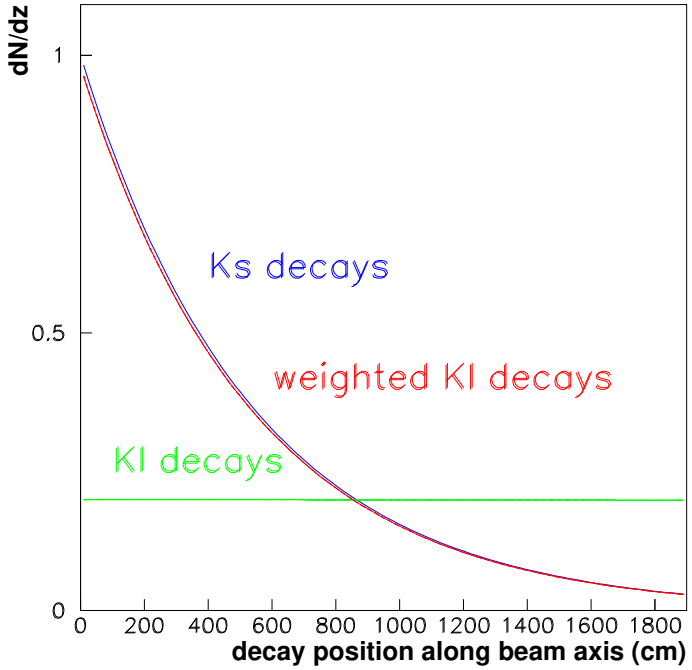
- Centre of gravity $R_{COG} \leq 10$ cm

K impact point extrapolated to the calorimeter



Lifetime weighting principle

For given z: Acceptance $K_S = K_L$
But very different decay lengths:
$\tau_{K_L} \approx 600 \times \tau_{K_S}$



$\Rightarrow$ Different acceptances for K_S and K_L and large correction on R

Solution: Weight K_L events with

$$W = \frac{\pi\pi \text{ decay rate in } \mathrm{K_S} \text{ beam}}{\pi\pi \text{ decay rate in } \mathrm{K_L} \text{ beam}} \approx e^{-z/(\beta\gamma c)(1/\tau_{KS}-1/\tau_{KL})}$$

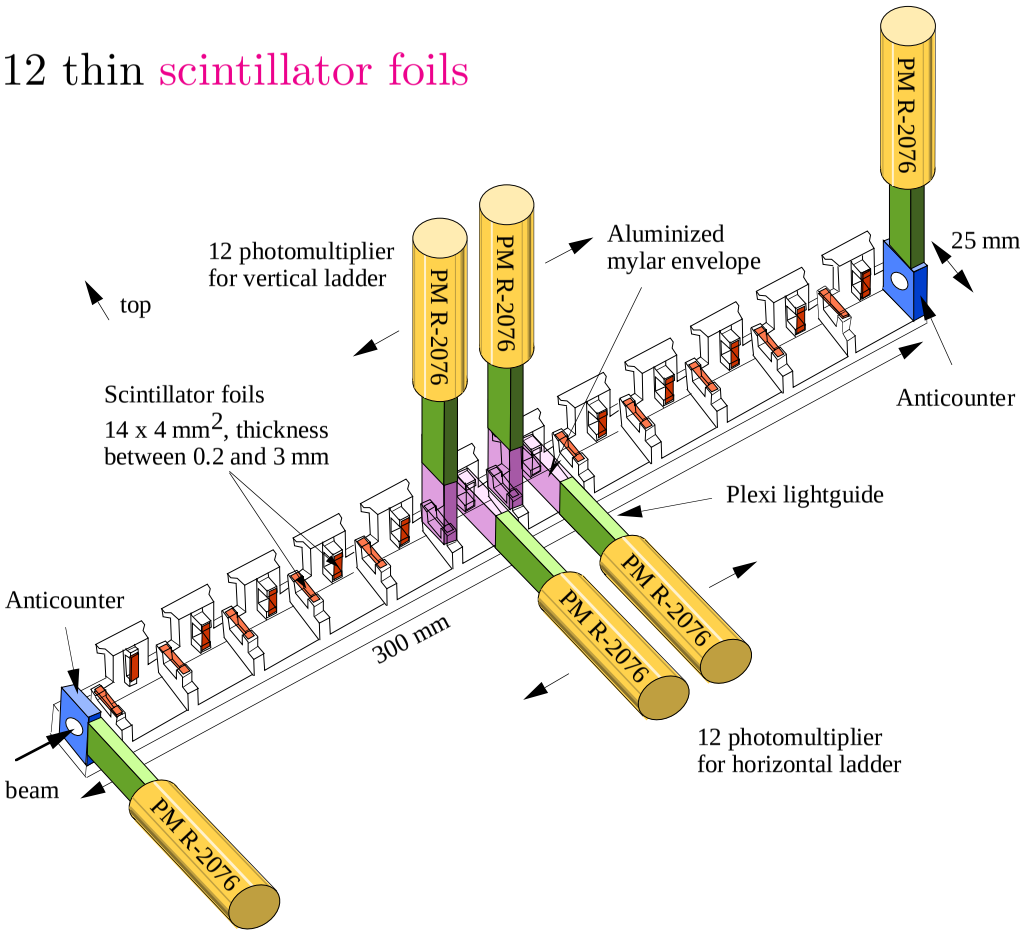
$\Rightarrow$ Same decay vertex distribution for K_S and weighted K_L

Acceptance correction cancels

Price: Increase in statistical error

The K_S proton tagger

2×12 thin scintillator foils

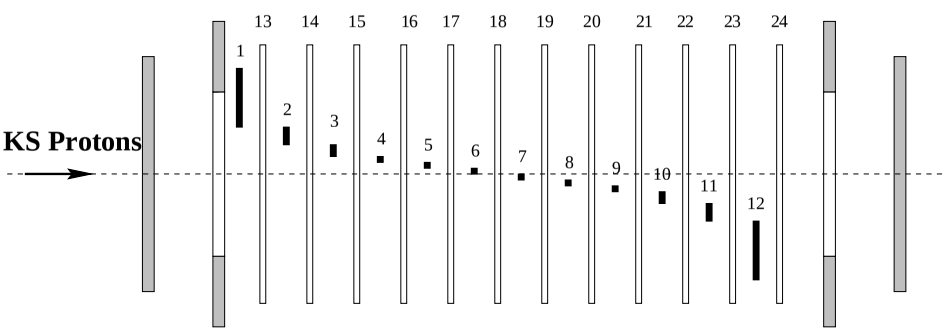


Proton rate: $\approx$ 30 MHz $\rightarrow$ split the intensity between foils

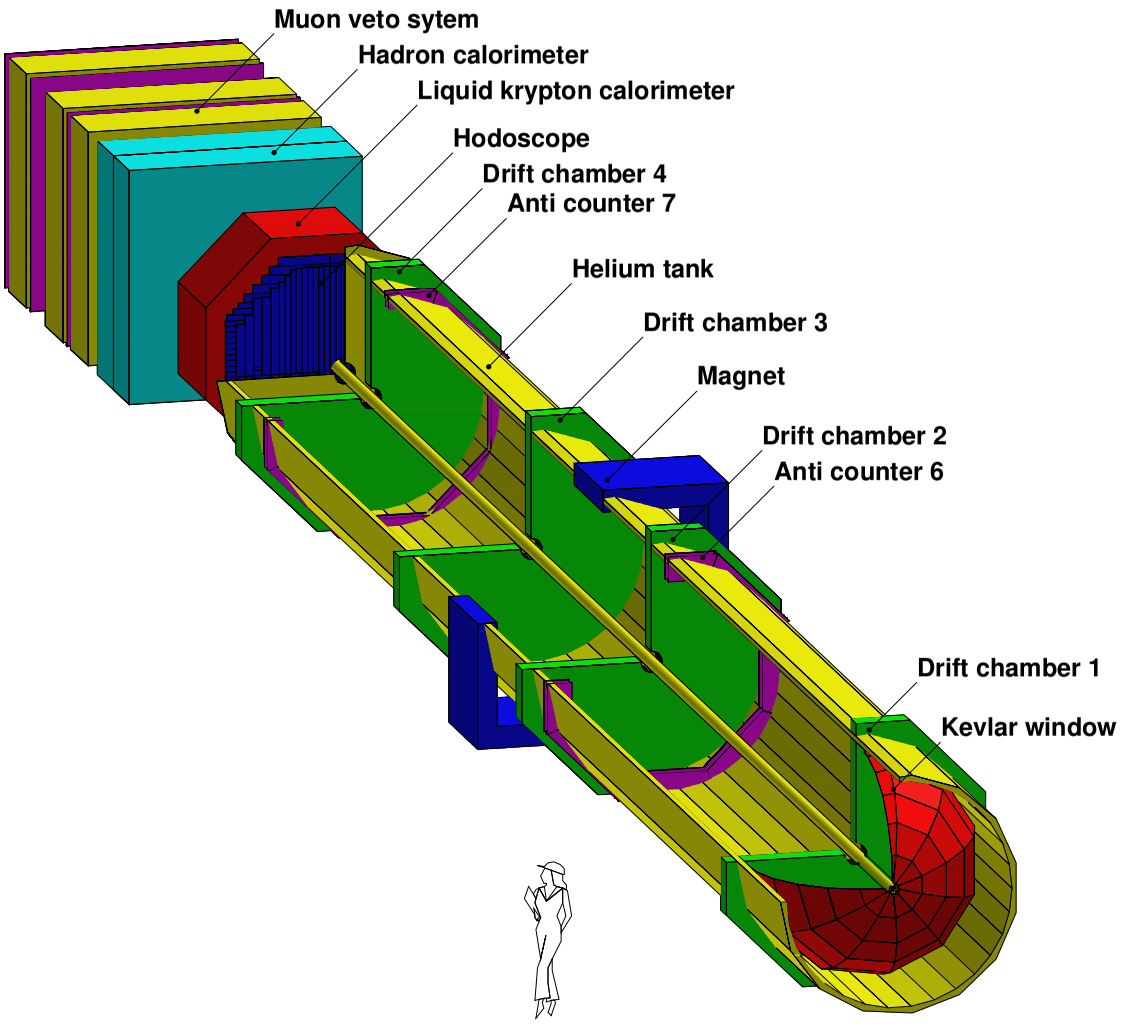
read-out by Flash-ADC 8 bits at 960 MHz

$\Rightarrow$ Time resolution : 140 ps

$\Rightarrow$ Double pulse separation : 4 ns



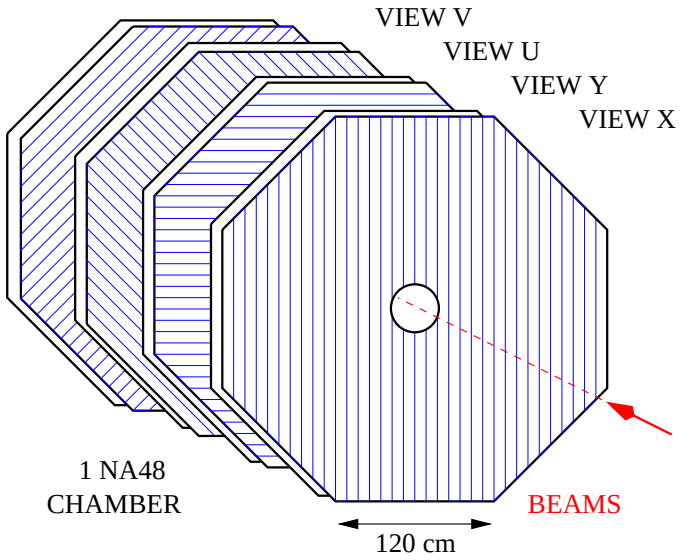
NA48 detector



- Magnetic spectrometer to detect $\pi^+\pi^-$ events
  + scintillator hodoscope for event time measurement
- Quasi homogeneous Liquid Krypton calorimeter to detect $\pi^0\pi^0$ events

The magnetic spectrometer

2×2 drift chambers + magnet $\rightarrow$ 265 MeV/c p_t kick.



- Each chamber has
  4×2 planes $\times$ 256 wires
  Good redundancy
- Drift time < 100 ns
- Space point resolution ≈ 100 μm

$$\sigma(P)/P \simeq 0.5\,\% \oplus 0.009\,P[\mathrm{GeV}/c]\,\%$$

(~ 1 % for 100 GeV/c track momentum)

LKr electromagnetic calorimeter

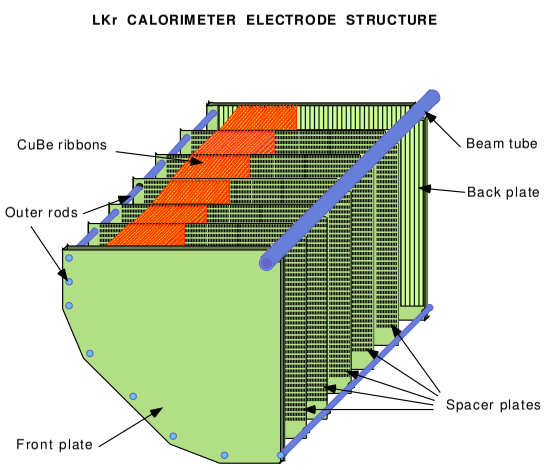
- Quasi-homogeneous detector

  10 m^3 liquid krypton (120 K)

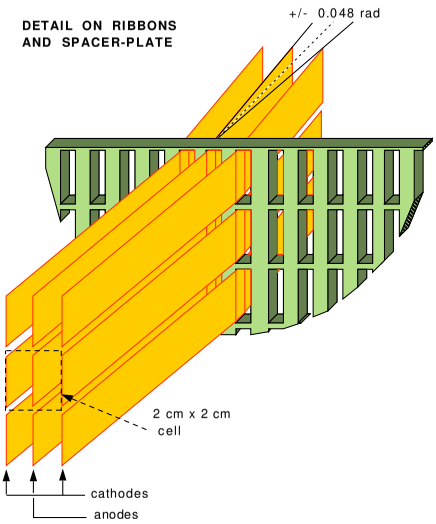
  ($X_0 = 4.7$ cm, $R_M = 6.1$ cm)

- 13212 cells
  - Granularity 2×2 cm^2
  - Depth 1.25 m ($\sim 27\ X_0$)

- Projective geometry pointing to decay region ($\sim$ 114 m upstream)
- Accordion geometry ($\pm$48 mrad) to diminish anode effects.



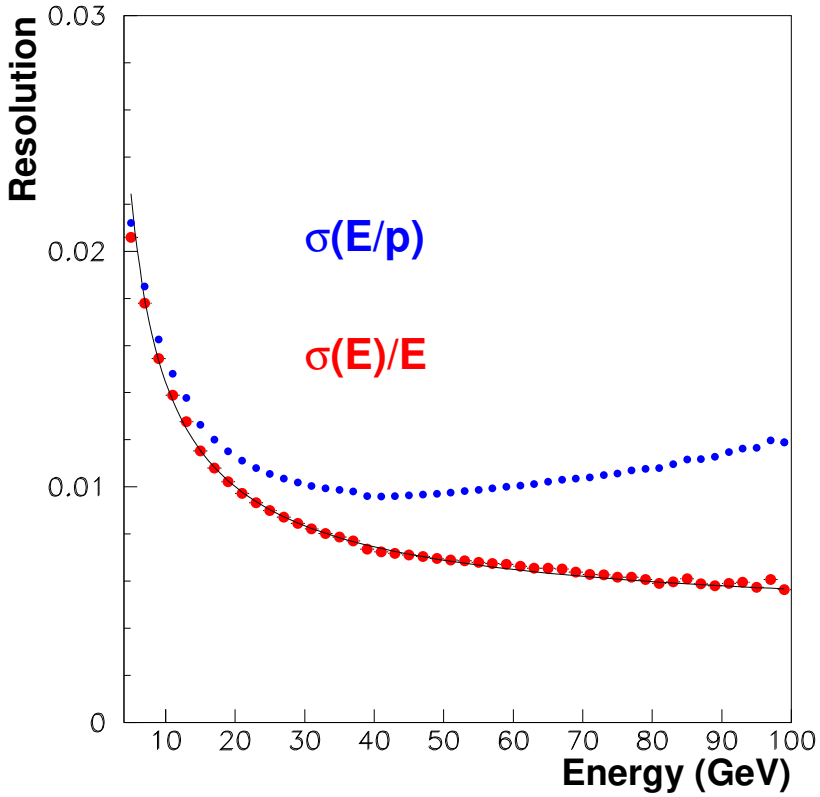
A quarter of calorimeter



Ribbons and a spacer

- Initial current read-out technique.

LKr energy resolution



Use large sample of $K_L \to \pi e \nu$ to study LKr energy response

Compare p from spectrometer and E from calorimeter

$E/p = 1$ for perfect detectors

$$\sigma(E)/E \simeq 3.2\%/\sqrt{E} \oplus 0.09/E \oplus 0.42\%$$ (E in GeV)

(better than 1 % for 25 GeV photons)

Triggers

Rate of K_L decays $\approx$ 500 kHz

$\pi^0\pi^0$ trigger

- Based on LKr information summed into projections
- Cut on total energy, decay vertex and number of photons
- Fully pipelined, no dead time
- Output rate $\approx$ 2 kHz
- Efficiency $(99.920 \pm 0.009)\%$
  ΔR negligible

$\pi^+\pi^-$ trigger

1. Level 1 :
   - Scintillator hodoscope + Total energy + hits in drift chambers
   - Output rate $\approx$ 100 kHz
   - Dead time: 0.5%
   - Efficiency $(99.535 \pm 0.011)\%$
2. Level 2 :
   - Fast track reconstruction
   - Cut on decay vertex position + invariant mass
   - Output rate $\approx$ 2 kHz
   - Dead time: 1.1%
   - Efficiency $(98.353 \pm 0.022)\%$

   $\Delta R = (-3.6 \pm 5.2) \times 10^{-4}$

Data Samples

- 1997 : $\approx$ 0.5 million $K_L \to \pi^0\pi^0$
  Result published in 1999

- 1998 : $\approx$ 1 million $K_L \to \pi^0\pi^0$
  Several improvements (trigger, DAQ, calorimeter)

- 1999 : $\approx$ 2 million $K_L \to \pi^0\pi^0$
  Further improvements in trigger and DAQ
  better data taking efficiency

  November 99 : Beam tube implosion $\Rightarrow$ Drift chambers damaged

  Took only neutral events data in 2000 (cross-checks + high intensity K_S runs)

3. Data Analysis

- Measure R in Kaon energy bins (5 GeV wide)
  $\Rightarrow$ insensitive to K_S-K_L difference in E spectrum
- Apply lifetime weighting to K_L
- Record dead time conditions
  $\approx$ 1.5% from $\pi^+\pi^-$ trigger
  $\approx$ 20% from drift chamber multiplicity limit
  and apply them offline to all events
  $\Rightarrow$ Minimise effect of K_S-K_L beam intensity difference

$$R = \frac{N(K_L \to \pi^0\pi^0)N(K_S \to \pi^+\pi^-)}{N(K_S \to \pi^0\pi^0)N(K_L \to \pi^+\pi^-)}$$

At first order, almost everything cancels in R
Check and evaluate second order effects.

1. Identify $\pi^+\pi^-$ and $\pi^0\pi^0$ and subtract residual backgrounds
2. Tag K_S and K_L decays and correct for misidentification
3. Define common decay region for $\pi^0\pi^0$ and $\pi^+\pi^-$ events to ensure flux cancellation
4. Compute residual K_S and K_L acceptance differences
5. Evaluate residual effect from accidental induced event losses

Statistical error on R from 98+99 data $\pm 10.1 \times 10^{-4}$

Warning :

All corrections/uncertainties are given on R

Don't forget that to go to ϵ'/ϵ
there is a factor 1/6 !

$$\epsilon'/\epsilon = \frac{1}{6}(1 - R)$$

$\pi^+\pi^-$ selection

$K_S \to \pi^+\pi^-$: negligible background

$K_L \to \pi^+\pi^-$: BR $\approx 0.2\%$

Backgrounds : Ke3 (BR $\approx 39\%$), Kμ3 (BR $\approx 27\%$)

e and μ rejection

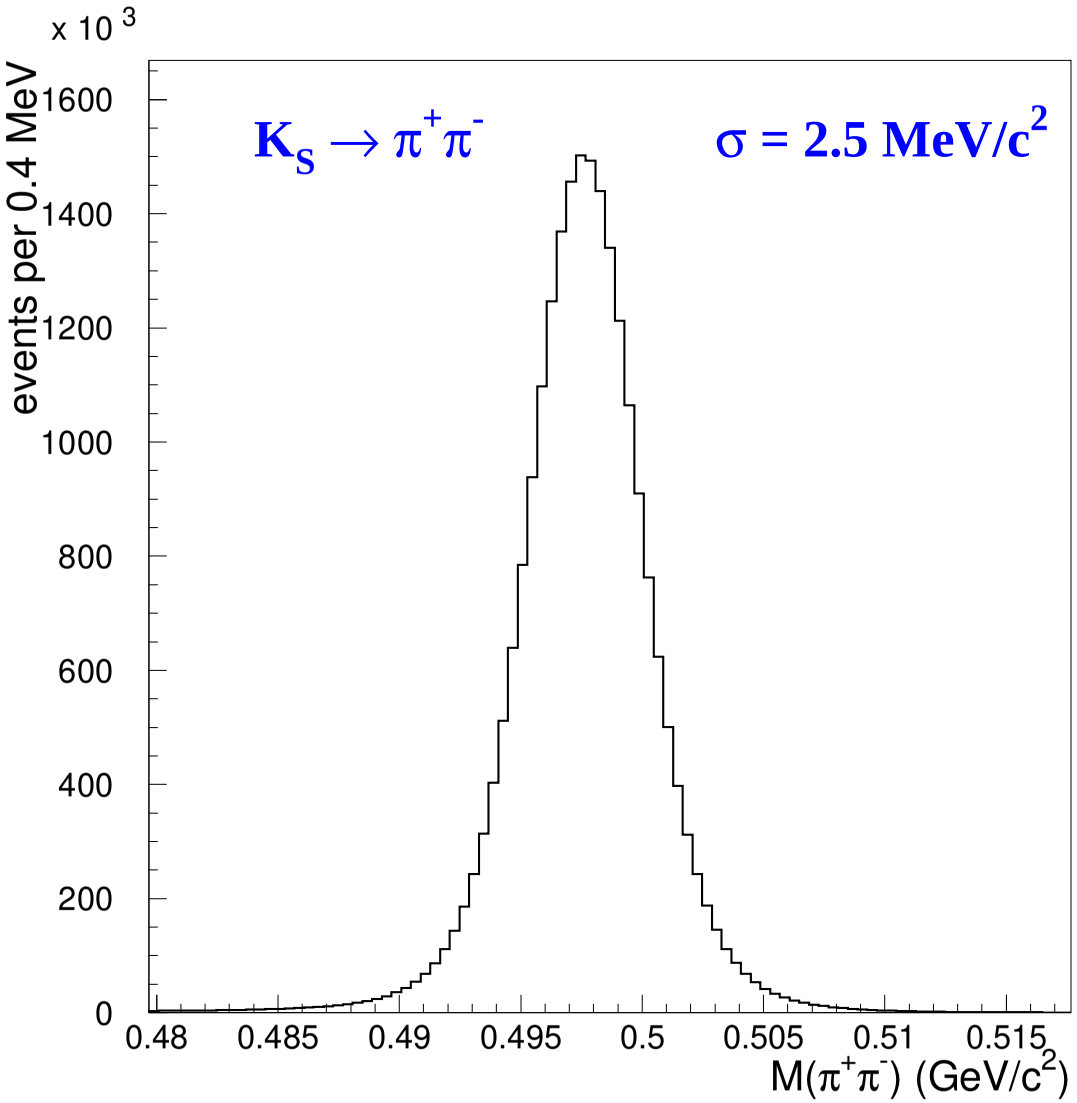
- E(LKr)/p < 0.8
- no hit in μ detector

kinematical cuts

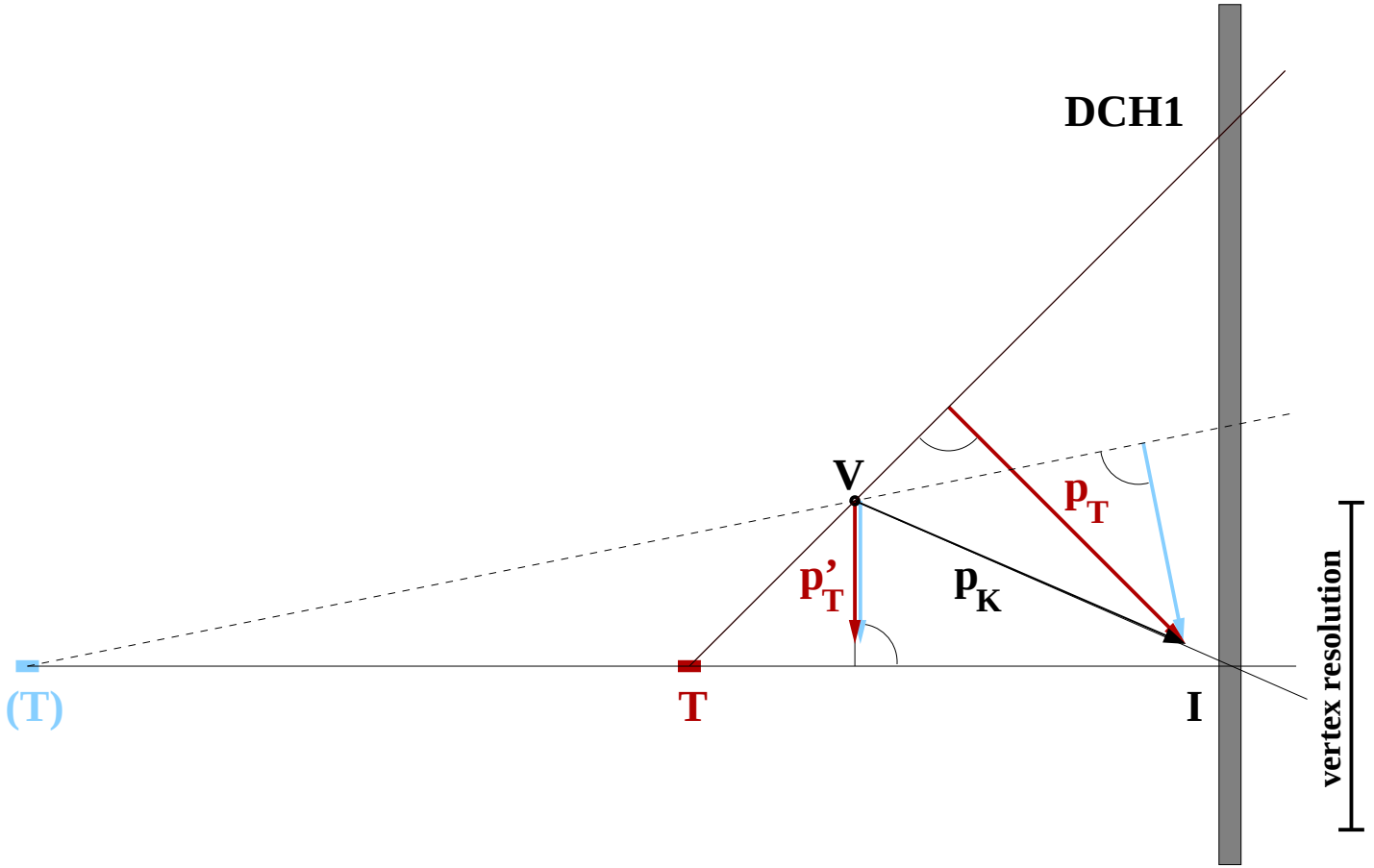
- $|M_{\pi\pi} - M_K| < 3 \times \sigma_M$, ($\sigma_M \approx 2.5$ MeV)
- $P_T'^2 < 200$ (MeV/c)^2
  $\propto$ transverse momentum of $\pi^+\pi^-$ / K line of flight
  ≈ 0 for two body decay, > 0 for Ke3, Kμ3
- $\frac{|p_1 - p_2|}{p_1 + p_2}$ <min(0.62,1.08-0.0052 $\times E_K$)

  ($\Leftrightarrow$ cut on $\cos(\theta^*)$)

$\pi^+\pi^-$ mass resolution



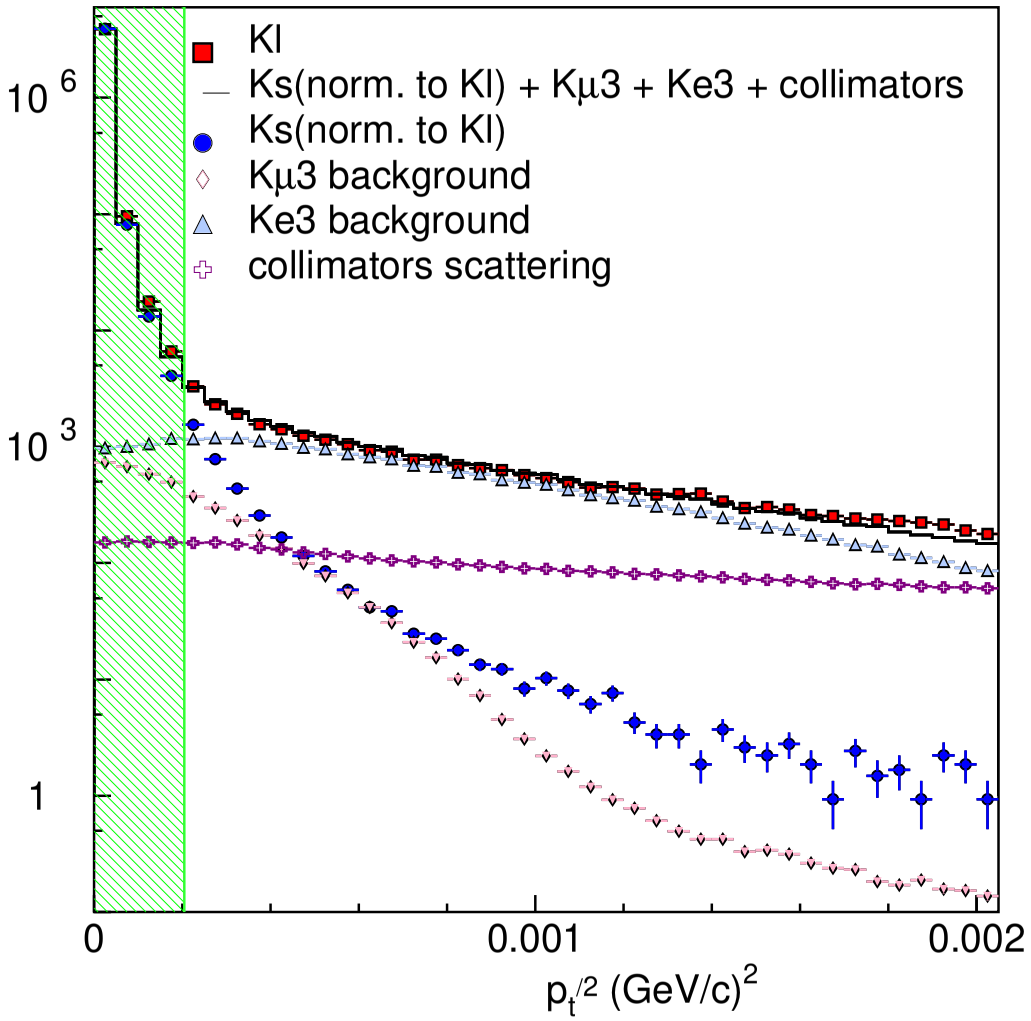
$P_T'^2$ definition



- Target distance is ~ 120 m $\Rightarrow$ P_T^2 very different for K_S and K_L
- $P_T'^2$: same resolution for K_S and K_L (dominated by vertex resolution)

$\pi^+\pi^-$ background subtraction

Estimate residual background under K_L signal using control regions in $M_{\pi\pi}$ and $P_T'^2$
and samples of identified Ke3 and Kμ3 data events.



$$\text{Background} = (16.9 \pm 3.0) \times 10^{-4}$$

(systematic error : changes in control regions, modelling of $P_T'^2$ shape)

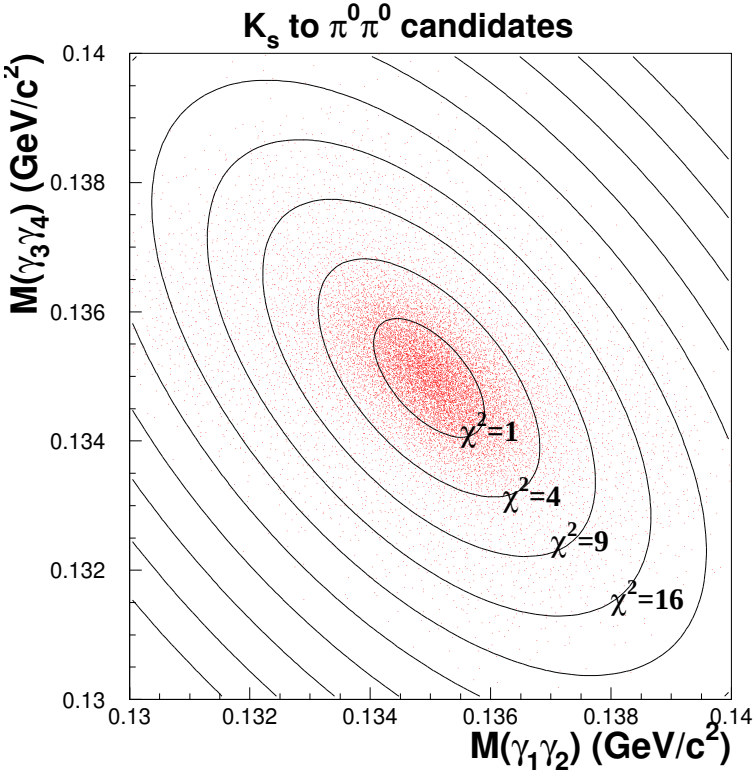
$\pi^0\pi^0$ selection

$K_S \to \pi^0\pi^0$: negligible background

$K_L \to \pi^0\pi^0$: BR $\approx 0.09\%$

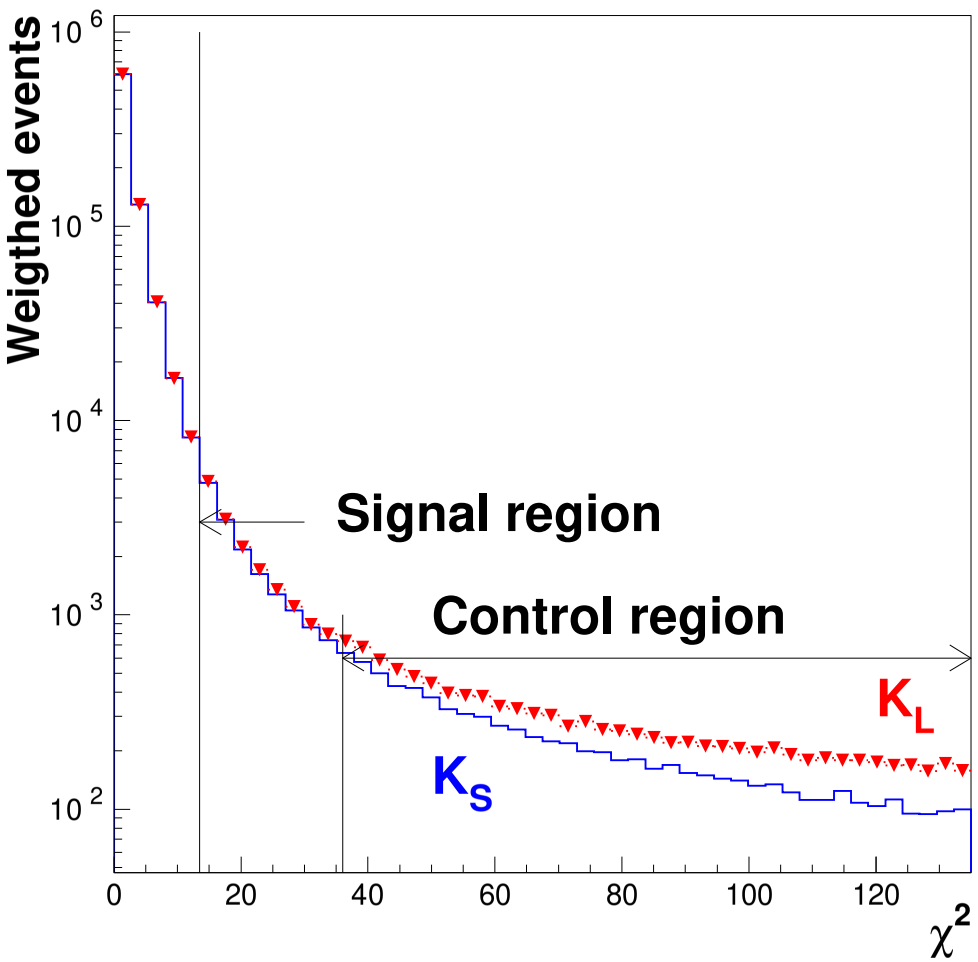
Background: $K_L \to 3\pi^0$ (BR $\approx 21\%$)

- 4 γ in LKr
- γ angle not directly measured
- (E_i, x_i, y_i) + K mass hypothesis
  $\Rightarrow$ D=$z_{LKr} - z = \frac{1}{M_K}\sqrt{\Sigma_{ij} E_i E_j d_{ij}^2}$
- Pair photons to get best π^0 masses
  $m_{ij} = \frac{1}{D}\sqrt{E_i E_j} d_{ij}$
  (resolution ≈ 0.9 MeV)
- To reduce background:
  Cut on χ^2 from π^0 masses
  Veto events with 5th cluster



$\pi^0\pi^0$ background subtraction

Estimate residual background under K_L signal using control region in χ^2
($3\pi^0$ background is $\approx$ flat)
$\pi^0\pi^0$ contribution in control region from resolution tails is derived from K_S events.

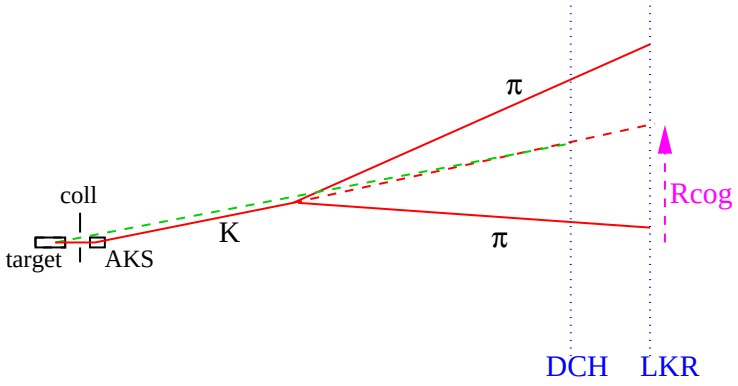


$$\text{Background} = (5.9 \pm 2.0) \times 10^{-4}$$

syst.error: uncertainty in background extrapolation (from MC)

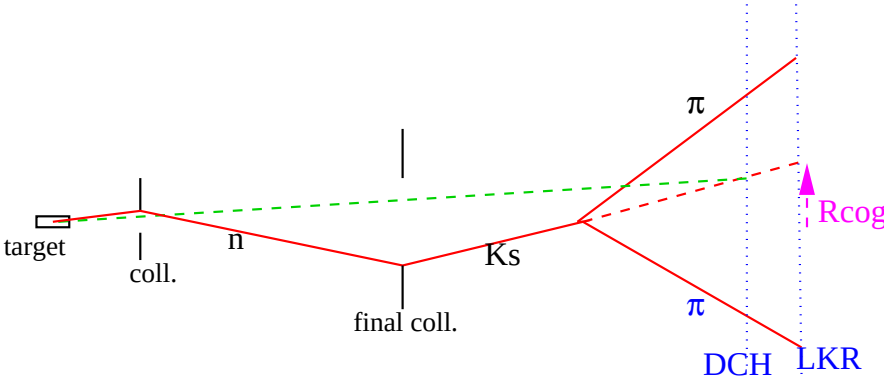
beam scattering backgrounds

K_S beam



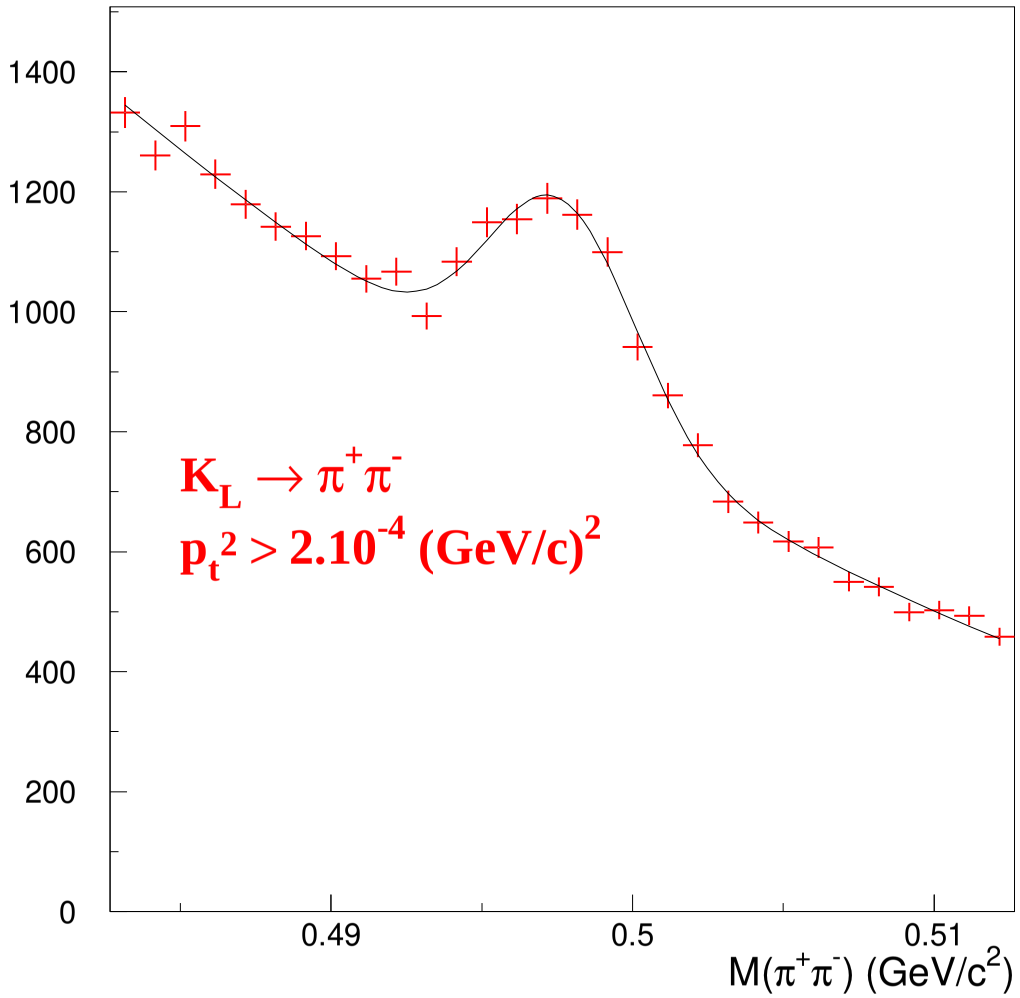
K_S scattering removed by Rcog cut
$\Rightarrow$ $\pi^+\pi^-$ and $\pi^0\pi^0$ symmetric
$\Rightarrow$ no effect on R

K_L beam



Background from beam scattering produces K_S in final collimator
Removed from $\pi^+\pi^-$ sample by $P_T'^2$ cut
Kept in $\pi^0\pi^0$ sample
$\Rightarrow$ correction

Measure collimator background in $\pi^+\pi^-$ mode from events at $P_T'^2 > 200$ (MeV/c)^2 with $M_{\pi\pi} = M_K$



Can also be estimated from $\pi^0\pi^0$ events as cross-check

Background in $\pi^0\pi^0 = (9.6 \pm 2.0) \times 10^{-4}$

Summary of background effects on R

Mode	$\Delta(R)$ (in 10^{-4} units)
$K_L \to \pi^+\pi^-$	
Ke3 and Kμ3 background	16.9 ± 3.0
$K_L \to \pi^0\pi^0$	
$3\pi^0$ background	-5.9 ± 2.0
Collimator scattering	-9.6 ± 2.0
Total	1.4 ± 4.1

K_S-K_L identification

$$\Delta t(\text{Kaon-proton}) \begin{array}{ccc} \leq & 2\text{ns} & \Rightarrow \quad K_S \\ > & 2\text{ns} & \Rightarrow \quad K_L \end{array}$$

2 possible mistakes

Danger only if $\pi^+\pi^- \neq \pi^0\pi^0$

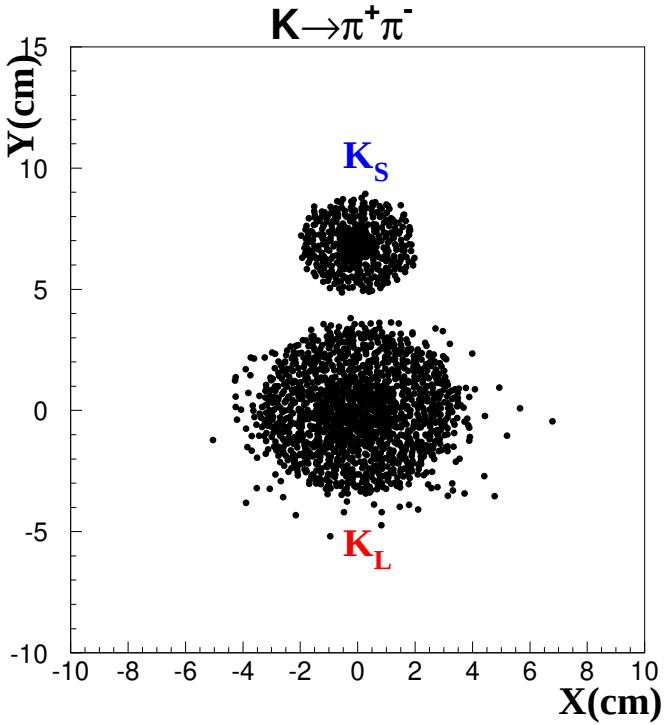
1. K_S mistagged as K_L: α_{SL}
   (tails in time measurement)

   $\Delta R \approx 6 \times \Delta\alpha_{SL}$

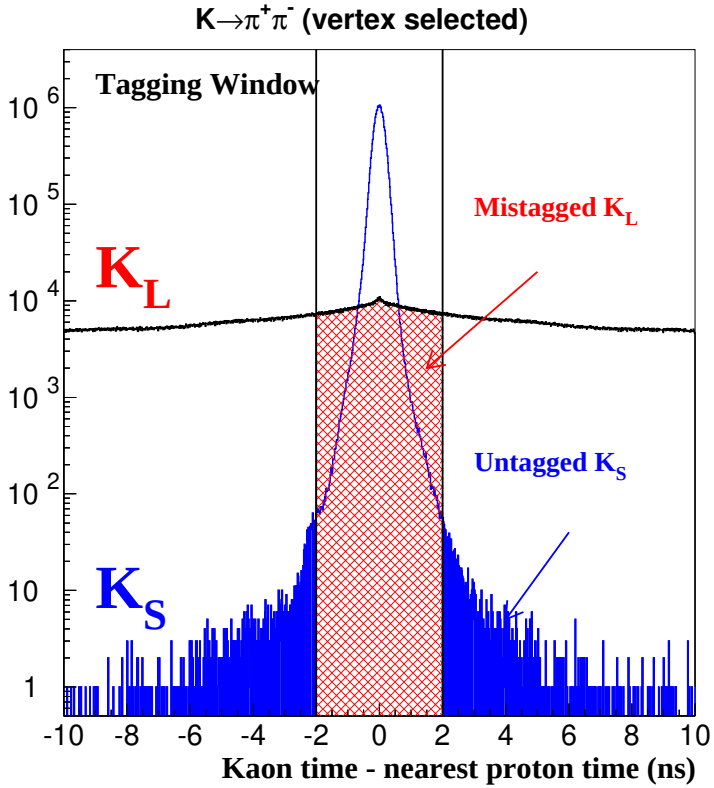
2. K_L mistagged as K_S: α_{LS}
   Accidental coincidence between K_L and a proton in tagger
   (rate $\approx$ 30 MHz)
   A priori symmetric $\pi^+\pi^-$-$\pi^0\pi^0$

   $\Delta R \approx 2 \times \Delta\alpha_{LS}$

Tagging performances from $\pi^+\pi^-$ events



Identify K_S, K_L with decay vertex position in transverse plane



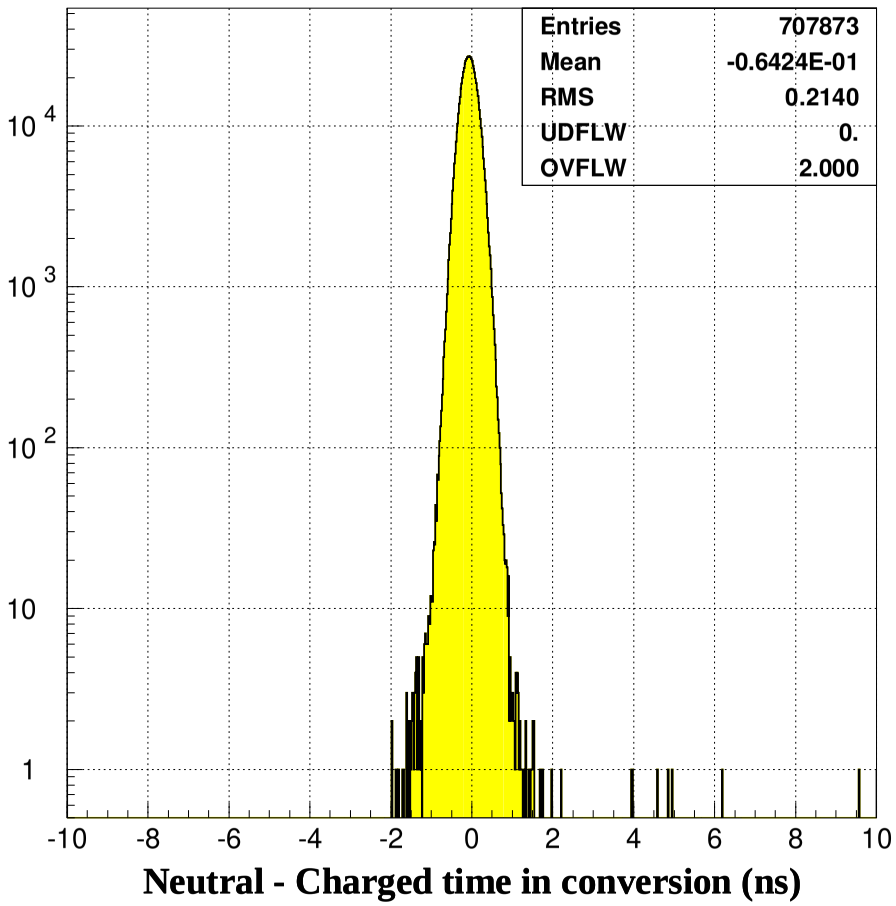
$$\alpha_{SL}^{+-} = 1.6 \times 10^{-4}$$
$$\alpha_{LS}^{+-} = (10.649 \pm 0.008)\%$$

Measuring $\Delta\alpha_{SL}$

α_{SL}^{+-} dominated by tagger inefficiency
($\pi^+\pi^-$ and $\pi^0\pi^0$ symmetric)

$\Delta\alpha_{SL} \leftrightarrow$ Difference in tails between
$\pi^+\pi^-$ and $\pi^0\pi^0$ event time measurements

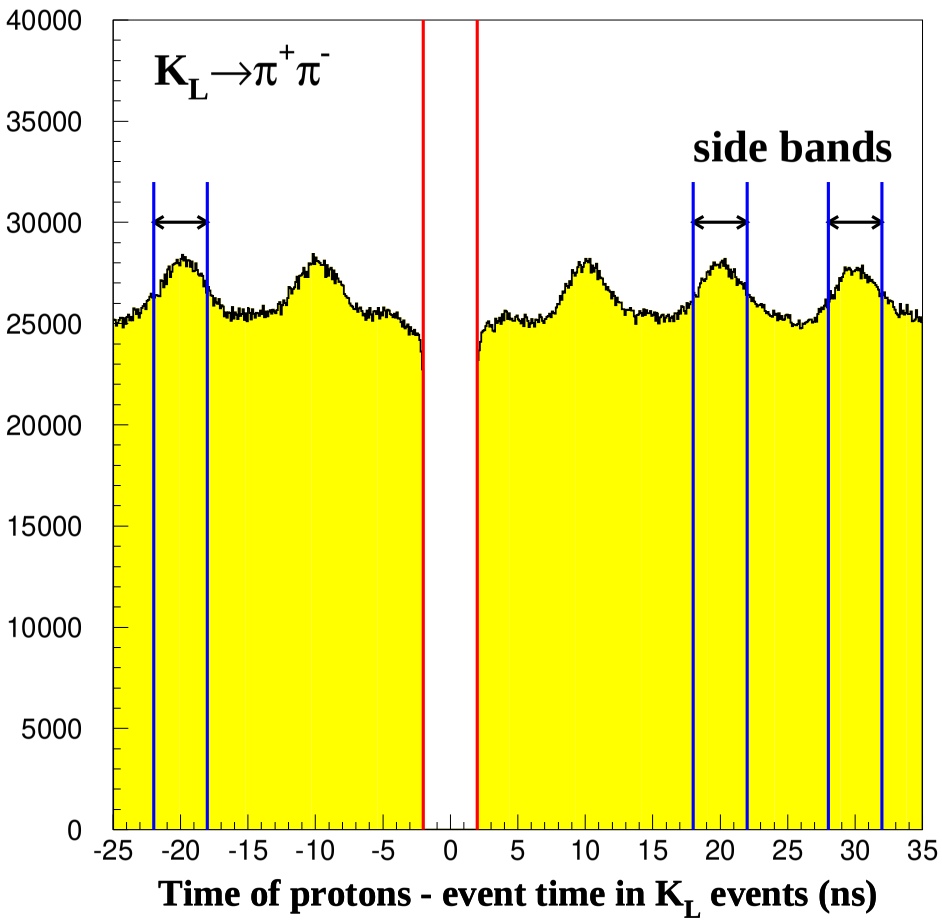
$\Rightarrow$ Compare directly charged and neutral
measurements using events with γ's and e^+e^-



$$\Delta\alpha_{SL} = (0 \pm 0.5) \times 10^{-4}$$

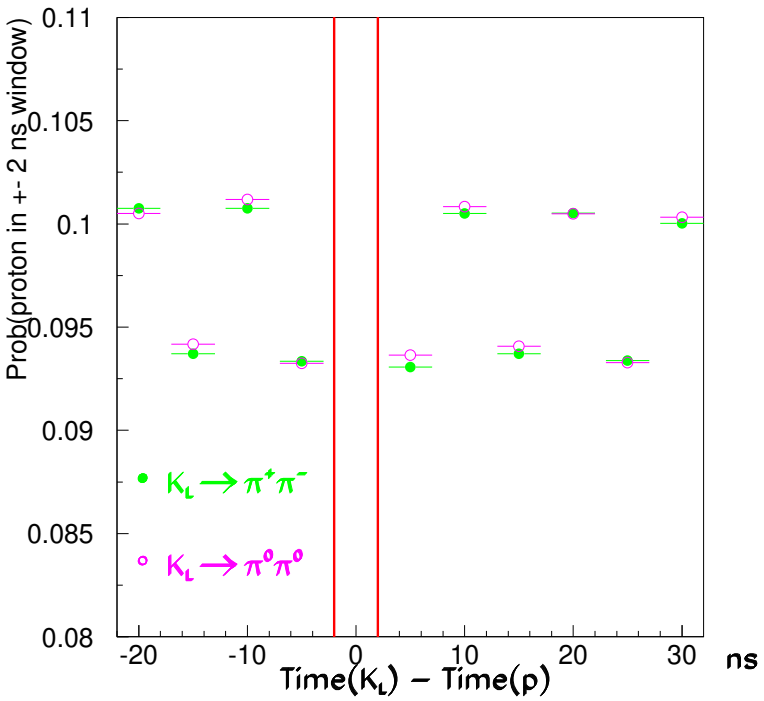
Measuring $\Delta\alpha_{LS}$

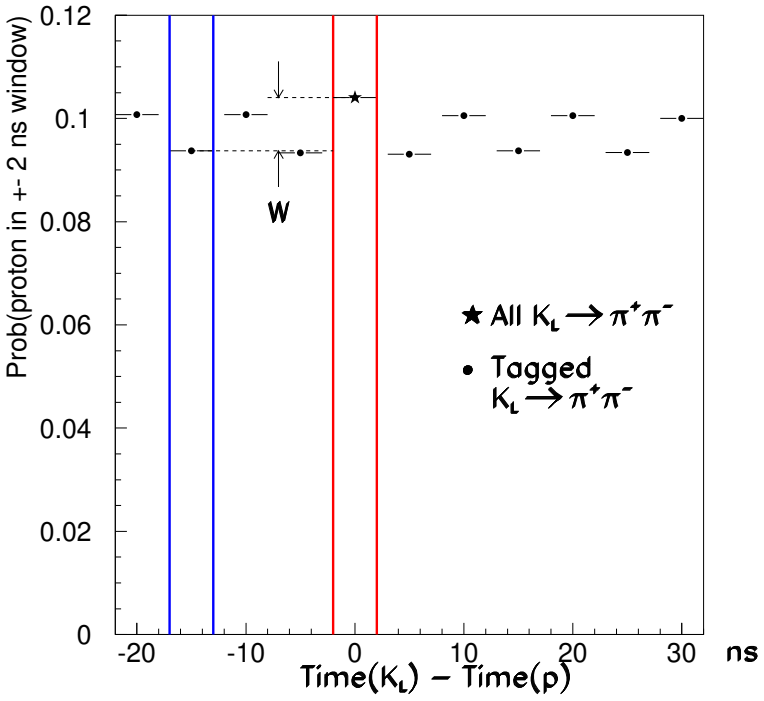
α_{LS} comes from fortuitous coincidences in tagger $\Rightarrow$ estimate $\Delta\alpha_{LS}$ using coincidence rate in tagging windows offset from the event time ("sidebands")



This is done for events tagged as K_L (no proton in central window)

Estimate of $\Delta\alpha_{LS}$





Using sidebands of tagger selected K_L to $\pi^0\pi^0$ and $\pi^+\pi^-$:

$\Delta = (3.0 \pm 1.0) \times 10^{-4}$

Extrapolation to central window (W)

$\pi^+\pi^-$: use vertex selected K_L

$\pi^0\pi^0$: use $3\pi^0$ events (only K_L)

$\Delta W = (1.3 \pm 1.1) \times 10^{-4}$

$$\Delta\alpha_{LS} = (4.3 \pm 1.8) \times 10^{-4}$$

(adding systematic error from choice of sideband windows: $\pm 1.0 \times 10^{-4}$)

Why is $\Delta\alpha_{LS} \neq 0$?

$\alpha_{LS} \propto$ Beam intensity (accidental coincidence rate)

Beam related activity $\Rightarrow$ Loss of good events

Loss $\propto$ Beam intensity

Losses higher for $\pi^+\pi^-$ than $\pi^0\pi^0$ $\quad \Delta = (1.4 \pm 0.7)\%$

$\Rightarrow$ Beam intensity slightly lower in selected $\pi^+\pi^-$ than in $\pi^0\pi^0$

Using random events overlay to simulate losses

$\Rightarrow$ predict $\Delta\alpha_{LS} = (3.5 \pm 0.5_{stat}) \times 10^{-4}$

very consistent with effect seen in data

Summary of tagging

- Data corrected for tagging misidentifications
- Error on R $\Leftrightarrow$ $\pi^+\pi^-$-$\pi^0\pi^0$ differences

	$\Delta(R)$ (in 10^{-4} units)
K_S Tagging inefficiency	
$\alpha_{SL}^{+-} = 1.6 \times 10^{-4}$	
$\Delta\alpha_{SL} = (0 \pm 0.5) \times 10^{-4}$	0 ± 3
K_L Accidental mistagging	
$\alpha_{LS}^{+-} = (11.649 \pm 0.008)\%$	
$\Delta\alpha_{LS} = (4.3 \pm 1.8) \times 10^{-4}$	8.3 ± 3.4
Total	8.3 ± 4.5

Decay region definition

Decay region is defined by applying cuts on the reconstructed kaon energy and the decay vertex position

This definition should be the same for $\pi^+\pi^-$ and $\pi^0\pi^0$ events
Otherwise, the kaon flux does not cancel in R

$\Rightarrow$ Need to understand in details Energy and Decay vertex computations

Energy and decay vertex computations

1. $\pi^+\pi^-$
   - z_{vertex} from track segments before magnet
   - E_K recomputed assuming Kaon mass from momentum ratio and track opening angle before magnet

   $\Rightarrow$ Computations based on Spectrometer geometry

2. $\pi^0\pi^0$
   - D(LKr-vertex)= $\frac{1}{M_K}\sqrt{\Sigma_{ij}E_iE_jd_{ij}^2}$

     (Energy scale)$\times$(Transverse size scale)
   - Fix transverse size of LKr
   - Adjust Energy scale to reconstruct nominal AKS anticounter position

     10^{-4} on energy scale $\Leftrightarrow$ 1 cm on vertex position

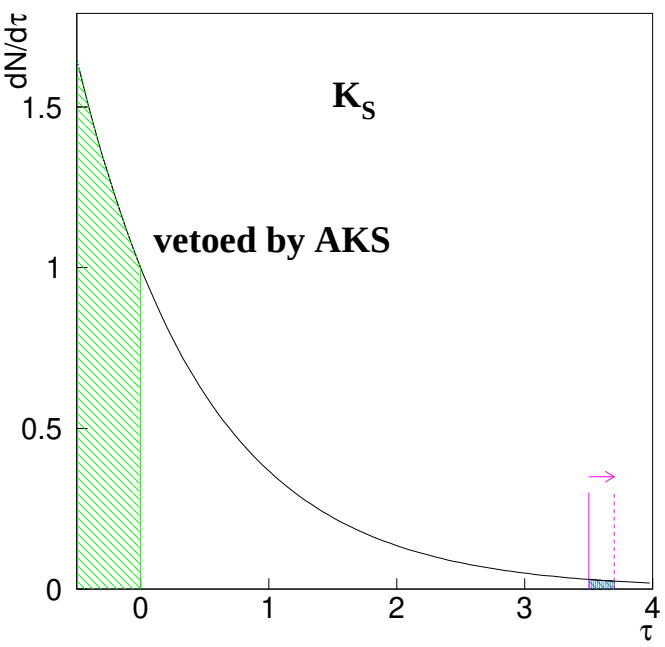
Detector geometry

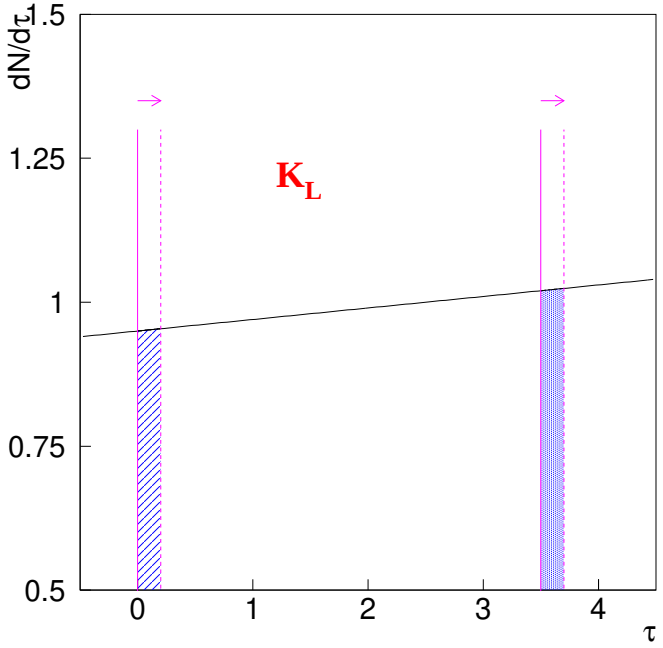
- Z positions known to $\approx$ 1 mm
- Transverse size known to :
  - Spectrometer $\approx$ 100 μm/m (10^{-4})
  - LKr $\approx$ 300 μm/m (after cool down)

    Checked with electron tracks using spectrometer as reference

Effect of error in energy scale $\pi^0\pi^0$ case

E $\rightarrow$ E$\times$(1+α) and D $\rightarrow$ D$\times$(1+α) $\Rightarrow \tau \rightarrow \tau + 15 \times \alpha$ (at E=100 GeV)





Sensitivity limited thanks to use of AKS to define beginning of K_S decay region

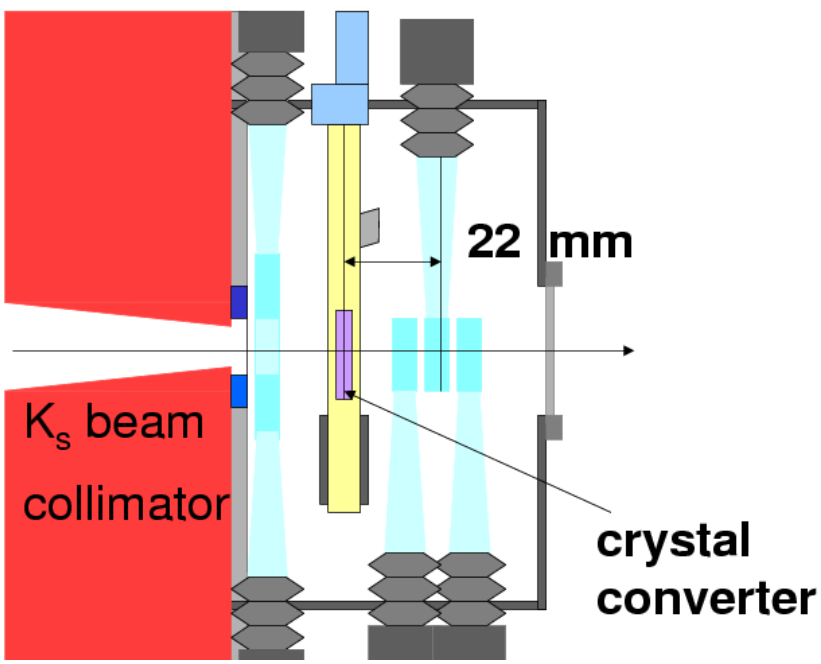
Typically $\Delta R \approx \alpha$
$\Rightarrow$ Energy scale correct to few 10^{-4}

Also sensitive to Non-Linearities ($\Leftrightarrow \alpha = \alpha(E_K)$)

The AKS counter

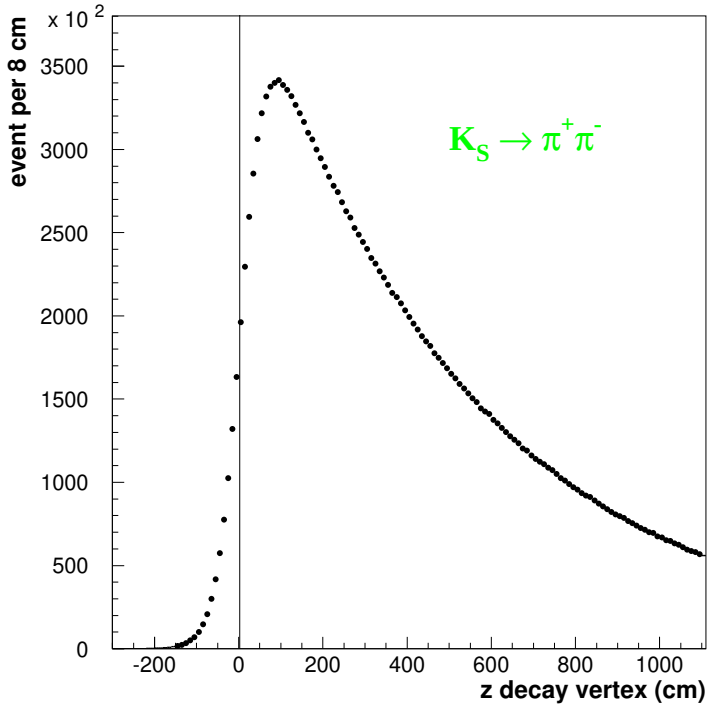
- Defines beginning of decay region for $\pi^+\pi^-$ and $\pi^0\pi^0$ K_S decays
- Used to fix the energy scale for $\pi^0\pi^0$ events
- Photon converter:
  - iridium crystal 3 mm thick, $(22 \pm .5)$ mm upstream of counter

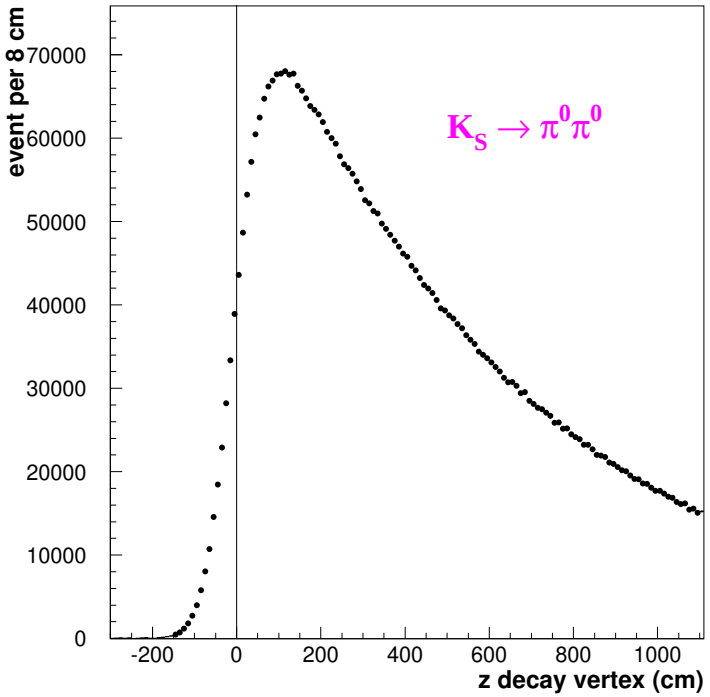
$\Rightarrow$ at 0 angle $\equiv 1.79$ X_0 instead of .98 X_0 for amorphous iridium



- very small veto inefficiency
- $\Delta R = (1.1 \pm 0.4) \times 10^{-4}$

Reconstruction of AKS position





$\pi^+\pi^-$: Check of geometry and reconstruction

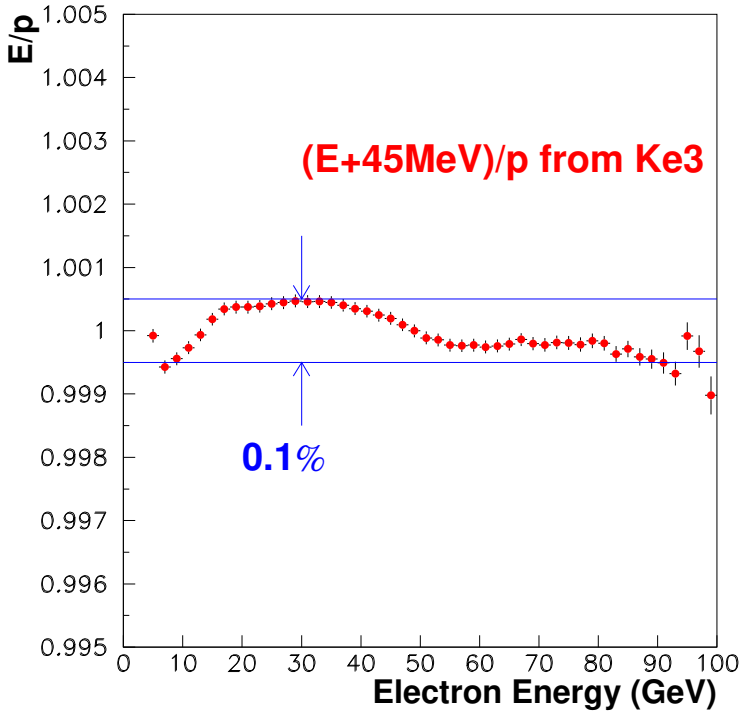
$\Rightarrow \Delta(z) = 2$ cm

$\Rightarrow \Delta(R) = (2 \pm 2) \times 10^{-4}$

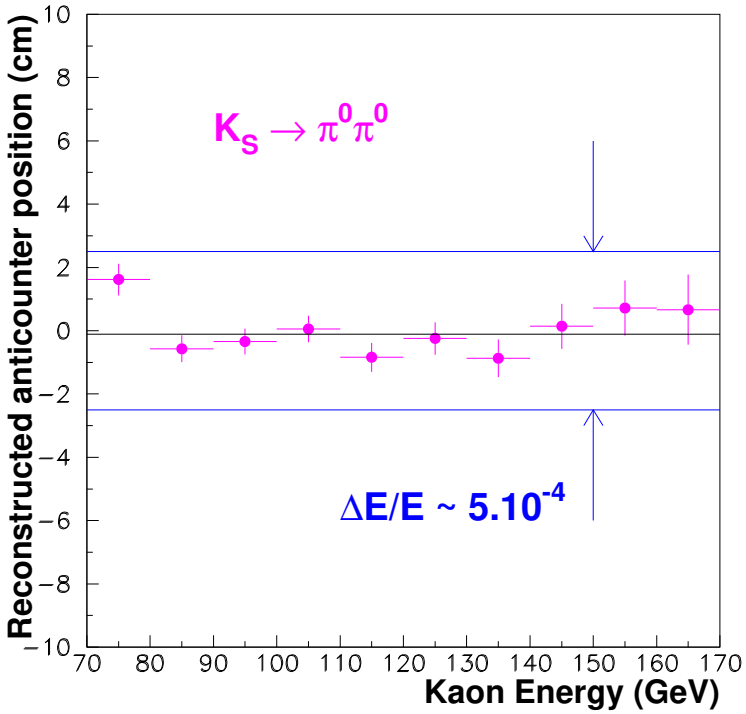
$\pi^0\pi^0$: Adjust energy scale to match nominal position (1 factor independent of energy)

Stability with time better than $\pm 5 \times 10^{-4}$

Non linearity checks

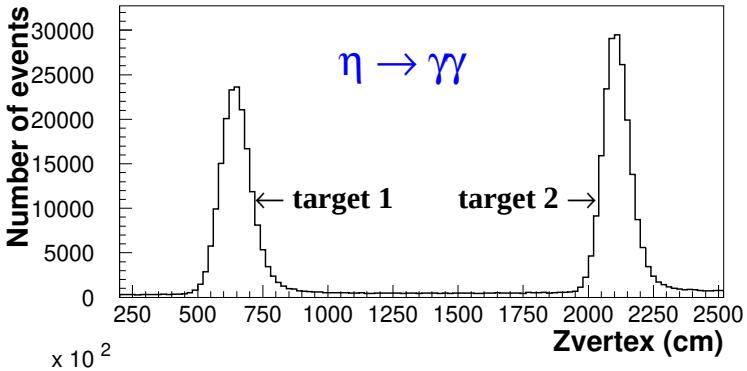


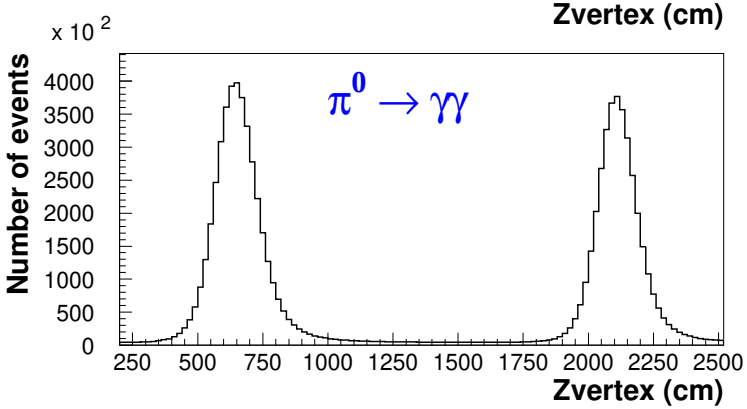
Electrons from Ke3 decays :
E/p constant within $\approx 0.1\%$
between a few GeV and 100 GeV

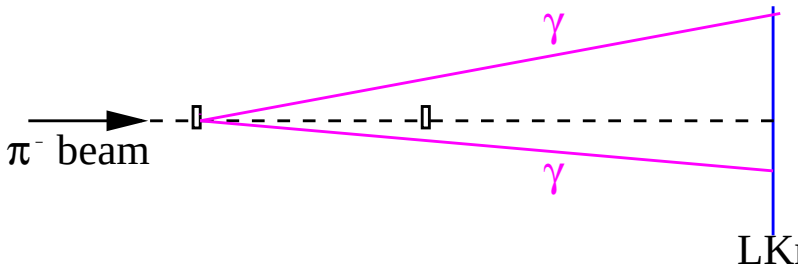


Overall Check :
Reconstructed AKS position
independent of K energy

Energy scale check







- Special run π^- beam directed to two thin targets
- Produce π^0 and η with known decay position
- Use $\gamma\gamma$ decays to reconstruct vertex (assuming π^0 or η masses)

  $D = \frac{1}{M}\sqrt{E_1 E_2} d_{12}$

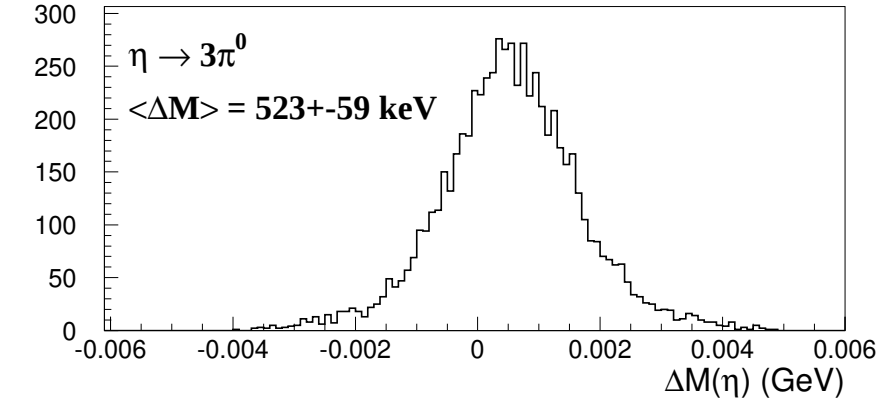
  Do we find the known target positions?

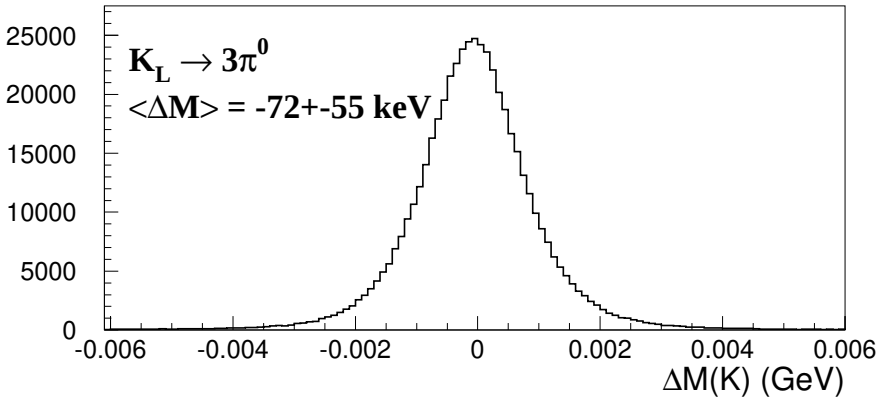
If yes, energy scale is OK

Can also check non-linearity and uniformity of energy response

Intermezzo: η mass measurement

PDG: $M_\eta = 547.30 \pm 0.12$ MeV





- Use $\eta \to 3\pi^0 \to 6\gamma$ decays
- Decay vertex from π^0 mass constraint

  $\Rightarrow$ Measure M_η / M_{π^0}

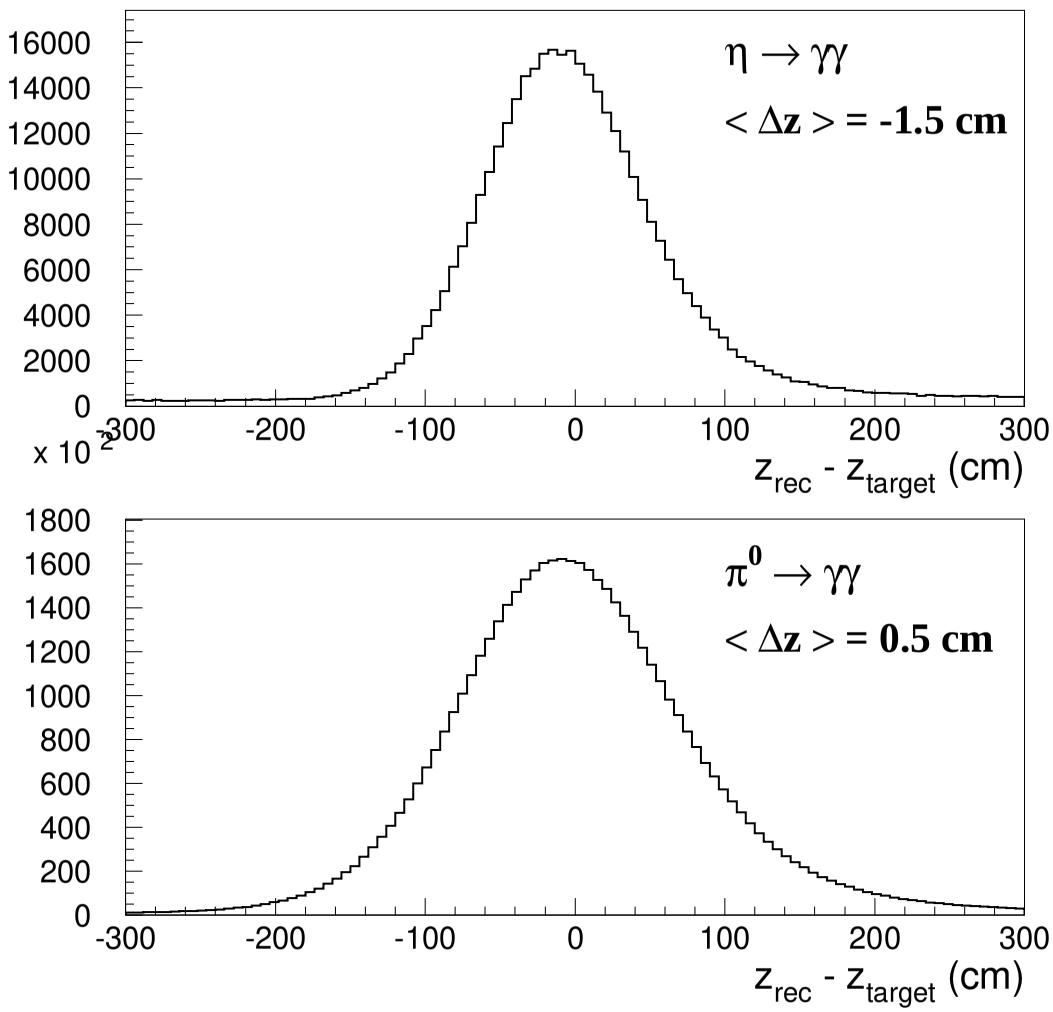
  Independent of energy scale!

- Check method on $K_L \to 3\pi^0$
- $\Delta M \equiv M_{\mathrm{NA48}} - M_{PDG}$

NEW Preliminary result $M_\eta = 547.823 \pm 0.020_{stat} \pm 0.055_{syst}$ MeV

Use this measurement to check energy scale with $\eta \to \gamma\gamma$

η target position check



$\Rightarrow$ OK to $\approx 2 \times 10^{-4}$

Same energy scale for both targets

Taking into account uncertainties from resolution modelling, K_S lifetime,...

Energy Scale uncertainty $= \pm 3 \times 10^{-4}$

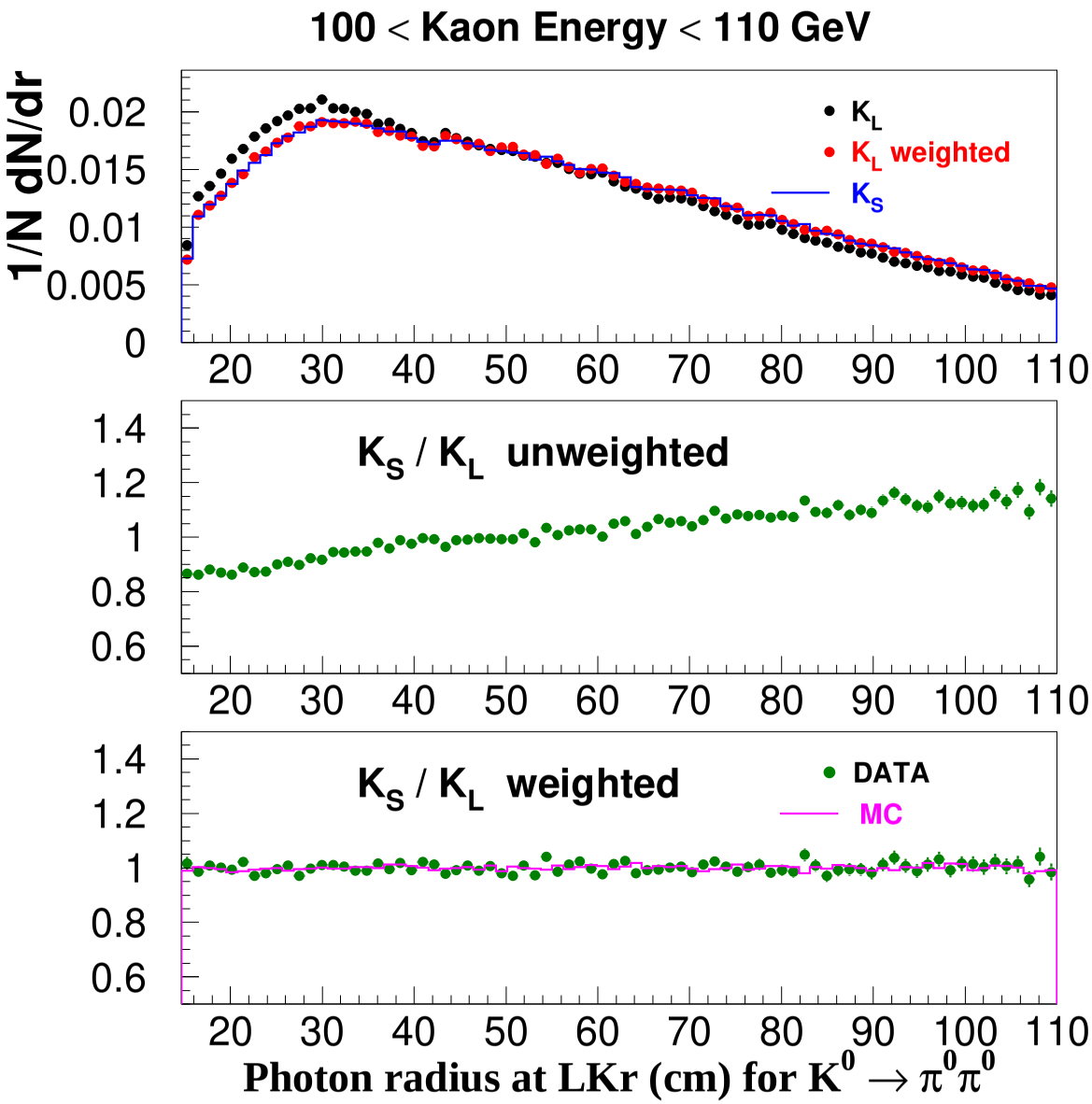
Summary on Decay Region Definition

	$\Delta(R)$ (in 10^{-4} units)
$\pi^+\pi^-$	
AKS position	± 2.0
Non-gaussian tails	± 2.0
Total	± 2.8
$\pi^0\pi^0$	
Energy scale	± 2.0
Non-linearities	± 3.8
Transverse size	± 2.5
Non-uniformities	± 1.5
Non-gaussian tails	± 1.2
Others	± 2.3
Total	± 5.8

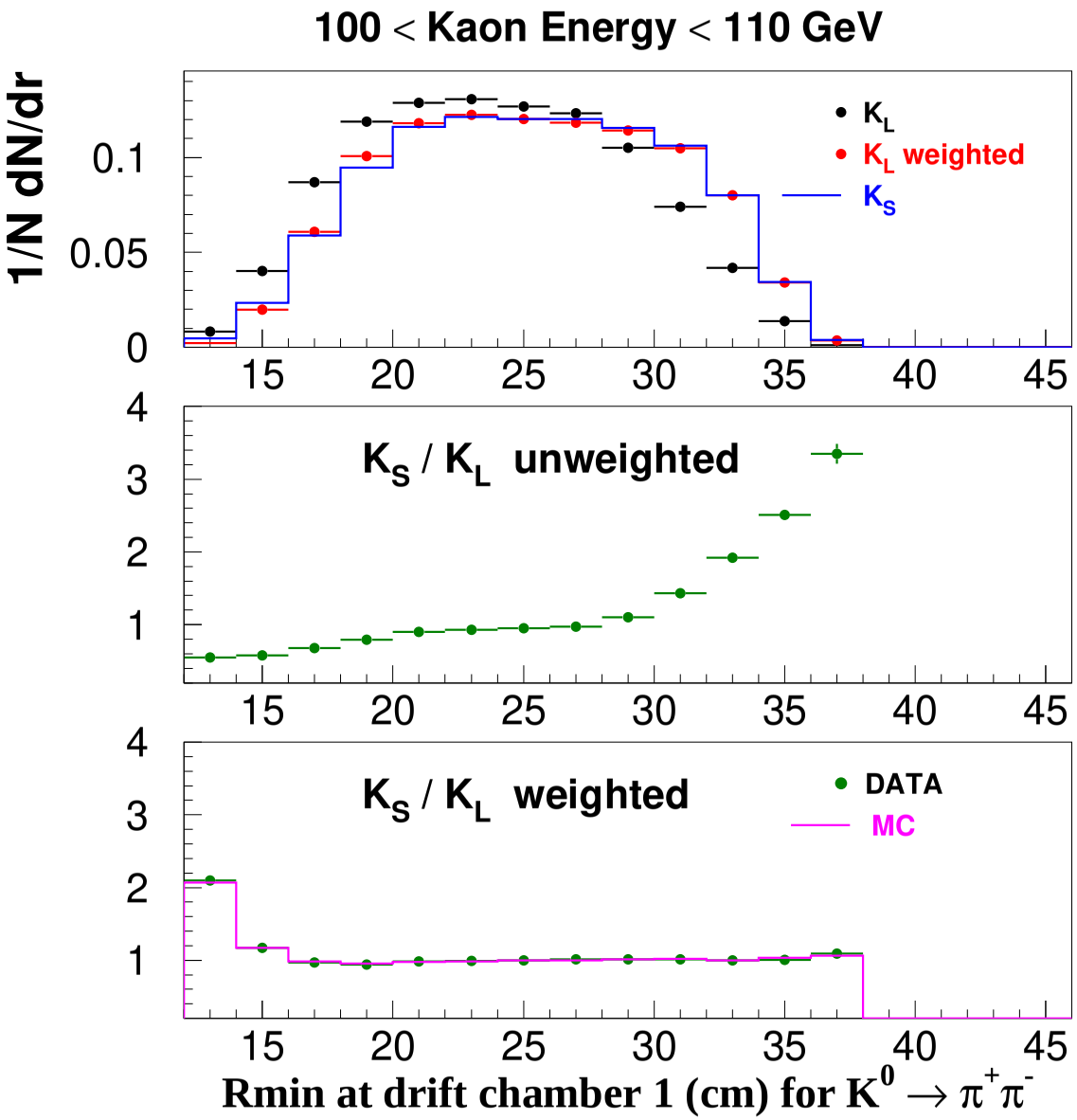
Acceptance Correction

K_L lifetime weighting

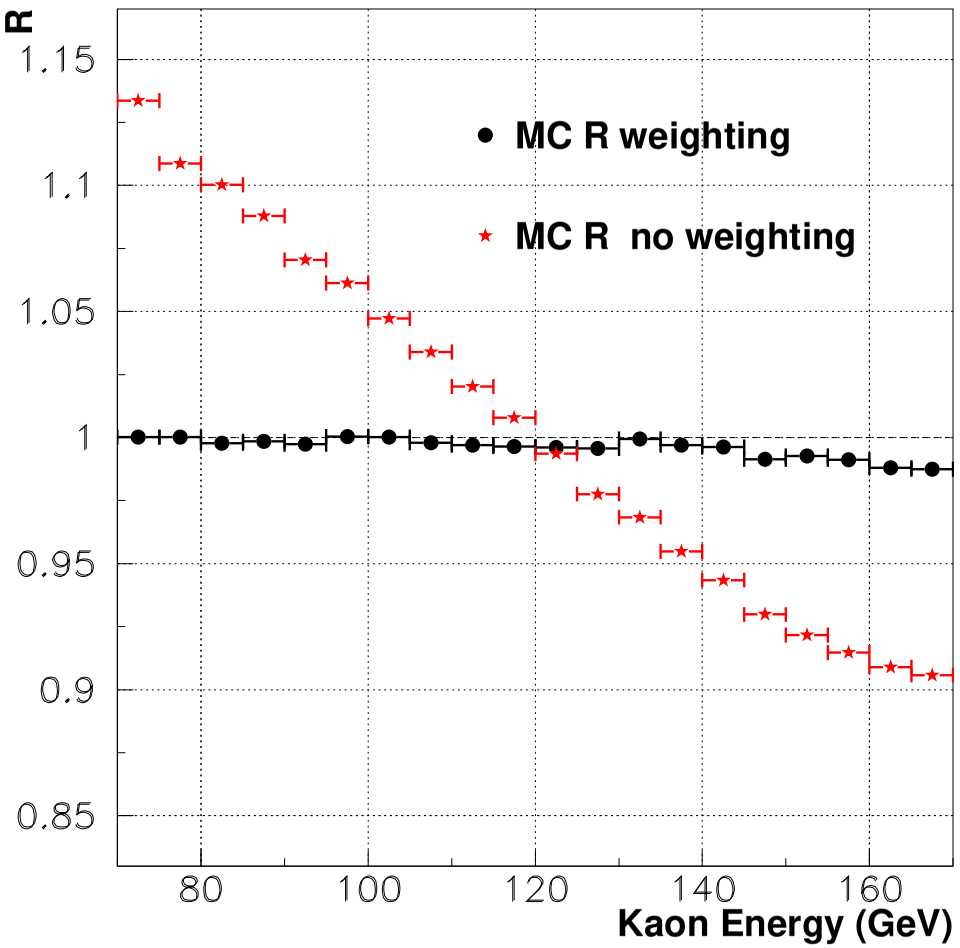
$\Rightarrow$ minimise K_L-K_S detector illumination difference and acceptance correction



Small residual effect from 0.6 mrad angle between K_L and K_S beams



Correction estimated using Monte-Carlo



Acceptance correction : $+26.7\times10^{-4}$

Uncertainties :

MC stat error: $\pm4.1\times10^{-4}$

Systematic error: $\pm4.0\times10^{-4}$

beam positions and shapes: $\pm3.3\times10^{-4}$

Comparison fast MC/GEANT based spectrometer simulation: $\pm2.3\times10^{-4}$

Accidental activity

Accidental activity from beam $\Rightarrow$ Event losses. Cancel at first order in R

Residual effect $\Delta R \approx \Delta(\pi^0\pi^0 - \pi^+\pi^-) \times \Delta(K_L - K_S)$

- $\Delta(\pi^0\pi^0 - \pi^+\pi^-)$ minimized by applying dead time conditions to all modes: $(1.4 \pm 0.7)\%$
- $\Delta(K_L - K_S)$ small by design of the experiment
  Simultaneous beams $\Rightarrow$ K_L and K_S events see the same activity, within 1% (checked directly in data)
  Lifetime weighting $\Rightarrow$ K_L and K_S events illuminate the same parts of the detector

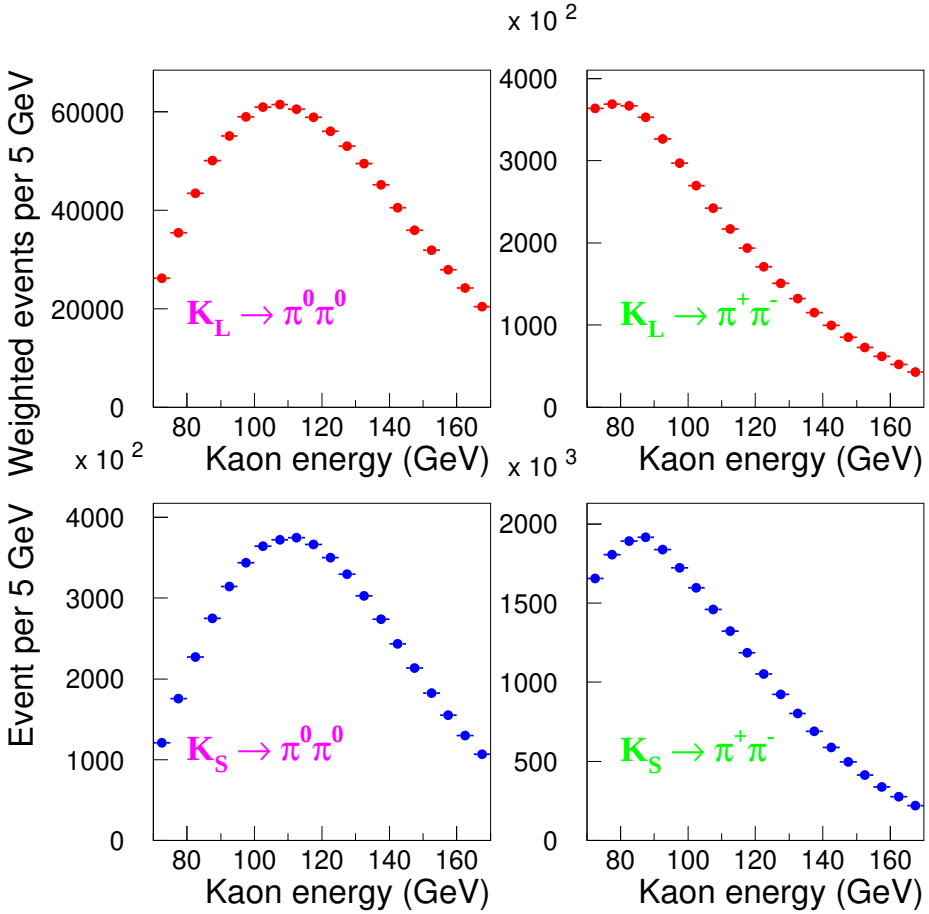
Uncertainty on R :

- Intensity difference $\Rightarrow$ $\Delta R = (0 \pm 3) \times 10^{-4}$
- Residual illumination difference $\Rightarrow$ $\Delta R = (0 \pm 3) \times 10^{-4}$
  (studied using random event overlays to $\pi\pi$ MC and data)

Summary of corrections and systematic errors

	$\Delta(R)$ (in 10^{-4} units)	
$\pi^+\pi^-$ background	16.9	± 3.0
$\pi^0\pi^0$ background	-5.9	± 2.0
beam scattering background	-9.6	± 2.0
Tagging inefficiency		± 3.0
Accidental tagging	8.3	± 3.4 (part. stat)
$\pi^+\pi^-$ scale	2.0	± 2.8
$\pi^0\pi^0$ scale		± 5.8
AKS inefficiency	1.1	± 0.4
Acceptance correction	26.7	± 4.1 (MC stat)
		± 4.0 (syst)
$\pi^+\pi^-$ trigger	-3.6	± 5.2 (stat)
Accidental event losses		± 4.4 (part. stat)
Total	35.9	± 12.6

Some uncertainties are limited by data statistics
($\pi^+\pi^-$ trigger efficiency measurement, accidental tagging,...)



Event statistics:

(corrected for mistagging)

$K_L \to \pi^0\pi^0$: 3.29×10^6

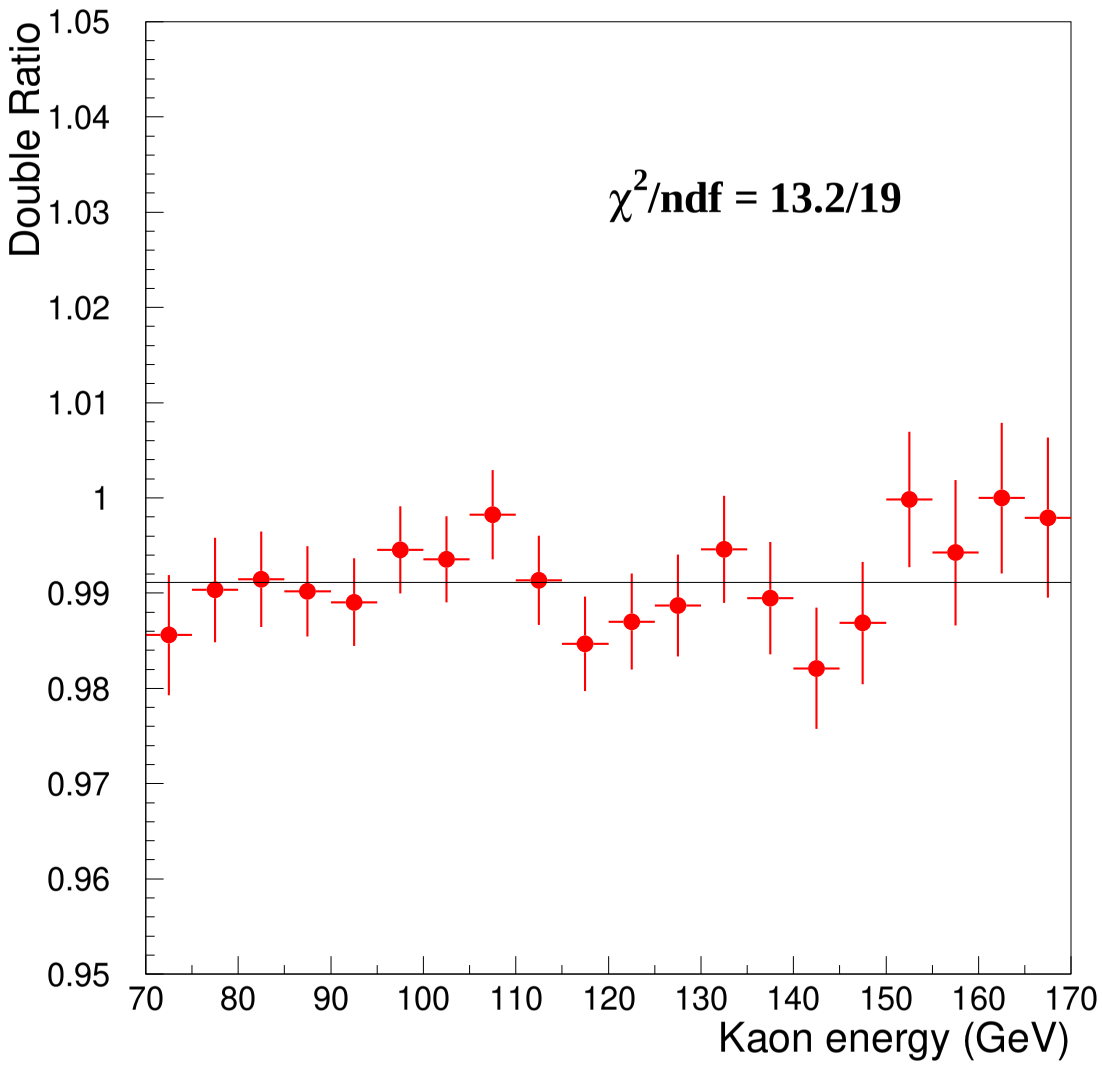
$K_S \to \pi^0\pi^0$: 5.21×10^6

$K_L \to \pi^+\pi^-$: 14.45×10^6

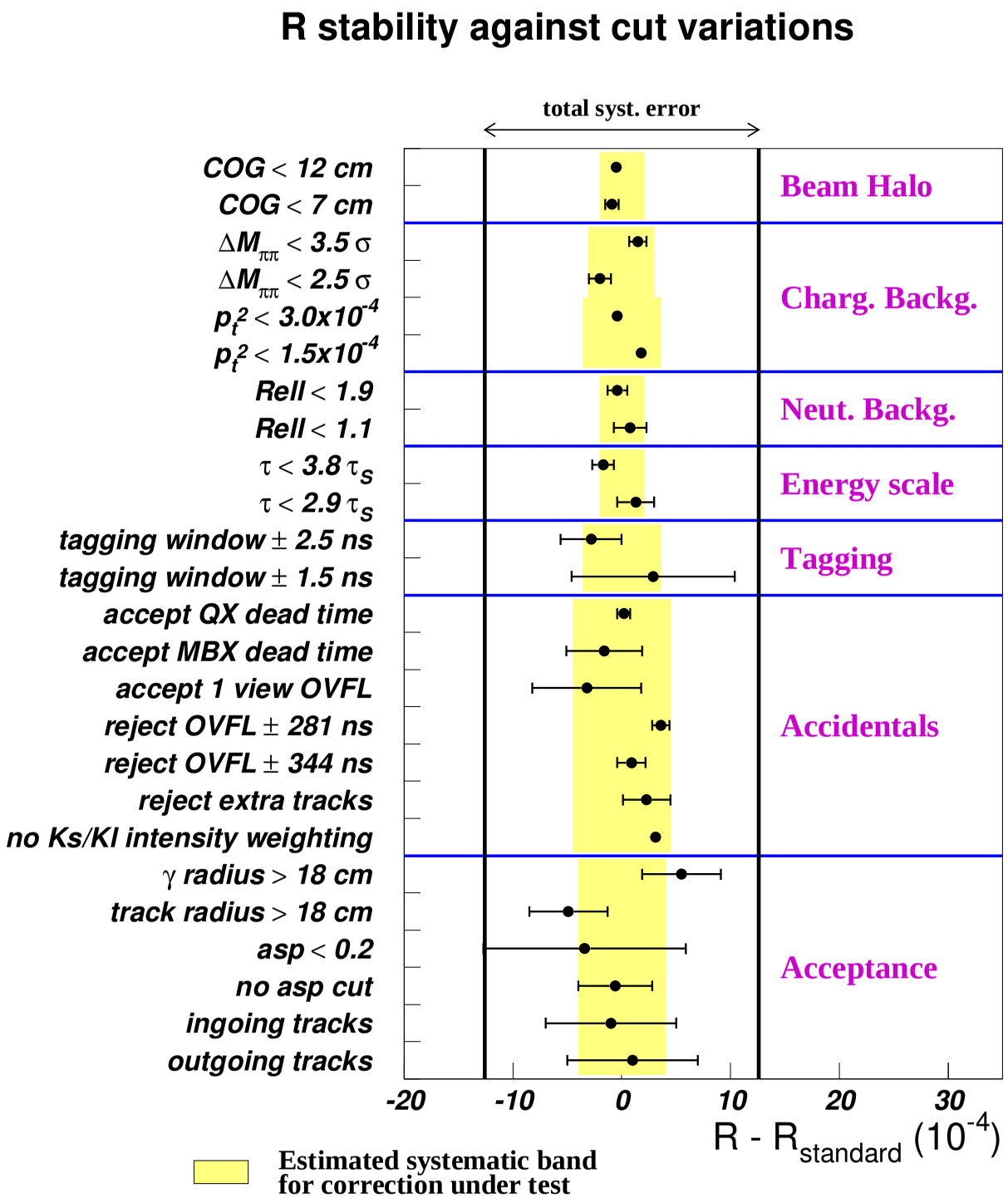
$K_S \to \pi^+\pi^-$: 22.22×10^6

Result

$$R = 0.99098 \pm 0.00101_{stat} \pm 0.00126_{syst}$$



Checks


R stability against cut variations
total syst. error
COG < 12 cm
COG < 7 cm
ΔM_ππ < 3.5 σ
ΔM_ππ < 2.5 σ
p_t^2 < 3.0x10^-4
p_t^2 < 1.5x10^-4
Rell < 1.9
Rell < 1.1
τ < 3.8 τ_S
τ < 2.9 τ_S
tagging window ± 2.5 ns
tagging window ± 1.5 ns
accept QX dead time
accept MBX dead time
accept 1 view OVFL
reject OVFL ± 281 ns
reject OVFL ± 344 ns
reject extra tracks
no Ks/Kl intensity weighting
γ radius > 18 cm
track radius > 18 cm
asp < 0.2
no asp cut
ingoing tracks
outgoing tracks
Beam Halo
Charg. Backg.
Neut. Backg.
Energy scale
Tagging
Accidentals
Acceptance
-20
-10
0
10
20
30
R - R_standard (10^-4)
Estimated systematic band
for correction under test

From 98+99 data:

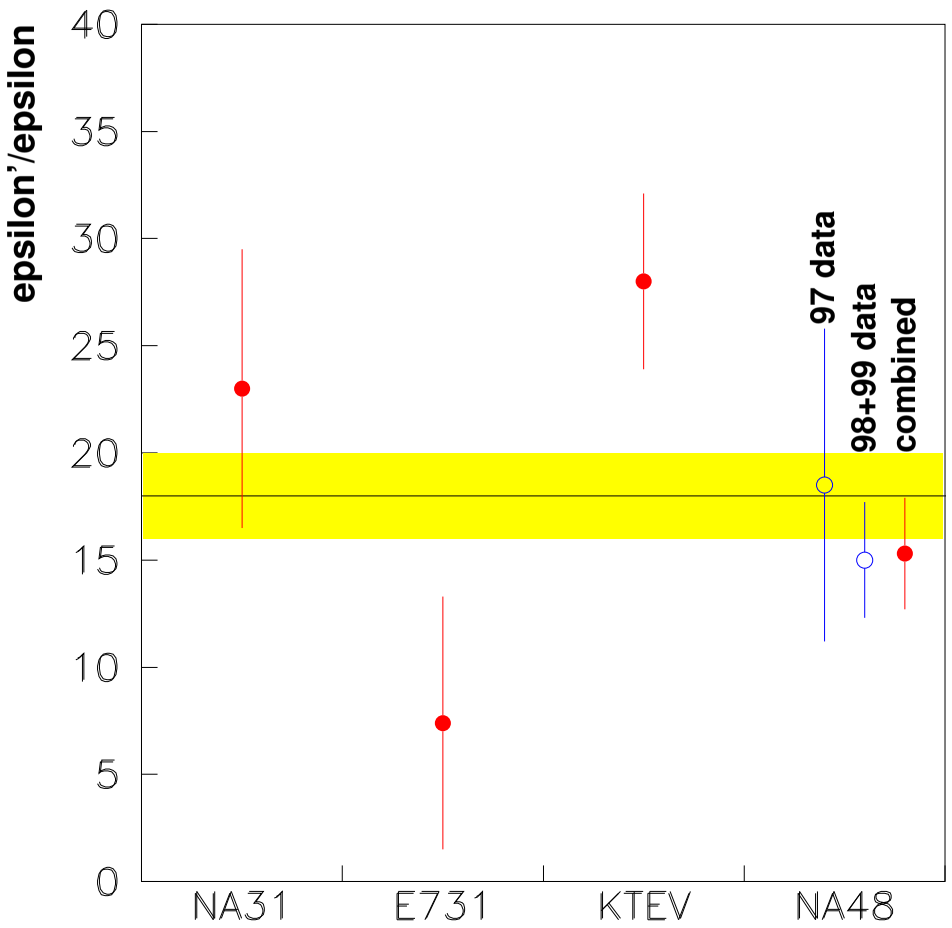
$$\epsilon'/\epsilon = (15.0 \pm 2.7) \times 10^{-4}$$

Combining with 97 result $(18.5 \pm 7.3) \times 10^{-4}$

$$\boxed{\epsilon'/\epsilon = (15.3 \pm 2.6) \times 10^{-4}}$$

(5.9 σ away from 0)

Experimental results comparison



Naive average : $\epsilon'/\epsilon = (18.0 \pm 2.0) \times 10^{-4}$
with $\chi^2/\text{ndf} = 10.8/3$

Wait for new KTeV result to conclude on world average

Prospects for ϵ'/ϵ

Drift Chambers being repaired

Data taking this summer (mid july-mid october)

Different beam conditions (spill)

97-99	2.4s every 14.4 s	(p energy = 450 GeV)
2001	5.2s every 16.8s	(p energy = 400 GeV)

$\Rightarrow$ better duty cycle

Hope to accumulate $> 1.5\times10^6$ $K_L \to \pi^0\pi^0$

at lower instantaneous intensity

$\Rightarrow$ complete statistics and verify result under different conditions

Conclusions

New NA48 result from 3 years of data taking

$$\boxed{\epsilon'/\epsilon = (15.3 \pm 2.6) \times 10^{-4}}$$

Direct CP violation in K_0 system

$$\frac{\Gamma(K^0 \to \pi^+\pi^-) - \Gamma(\overline{K^0} \to \pi^+\pi^-)}{\Gamma(K^0 \to \pi^+\pi^-) + \Gamma(\overline{K^0} \to \pi^+\pi^-)} = (5.0 \pm 0.9) \times 10^{-6}$$