Review of NA48 CP violation measurements with Neutral and Charged Kaons

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on Behalf of the NA48 and NA48/2 Collaborations

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

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OUTLINE

- Introduction
- NA48: the CP violation experiment
- History
- Detector
- **NA48**: Direct and Indirect CPV in $K^0 \rightarrow 2\pi$ decays
- **NA48/2**: Direct CPV in $K^{\pm} \rightarrow 3\pi$ decays
- Conclusions

CP Violation in Kaons

Kaons remain a privileged observatory for flavour physics phenomena: all the features of flavour physics are present (CPV of same size as in B)

- Very simple (minimal) system
- Very nicely accessible experimentally

- **All 3 types of CPV can be observed in K^0 decays**

➢ in $\overline{K^0}$-K^0 mixing ($\Delta S=2$, Indirect CPV: Re(ε))
➢ in the decay amplitudes ($\Delta S=1$, Direct CPV: Re(ε′))
➢ in the interference between decays with and without mixing (Im(ε) and Im(ε′))

- **Only Direct CP Violation occurs in $K^\pm$ decays (no mixing)**

- **Complementary observables to measure Direct CPV in Kaons**

➢ ε'/ε, A_g , Ultra-Rare decays

The NA48 experiment @ CERN

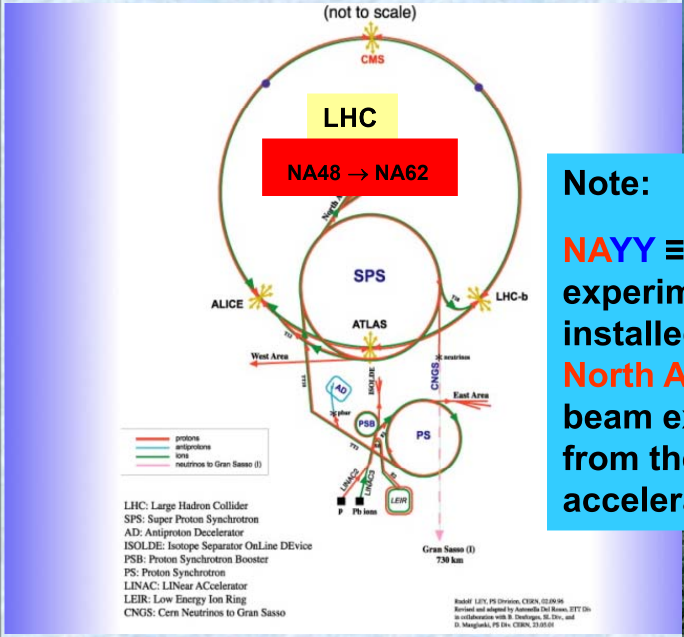
The CERN Accelerator Complex

The SPS at CERN produces 400 GeV/c protons using either a fast or slow extraction system

The SPS is used as well as injector for the LHC accelerator

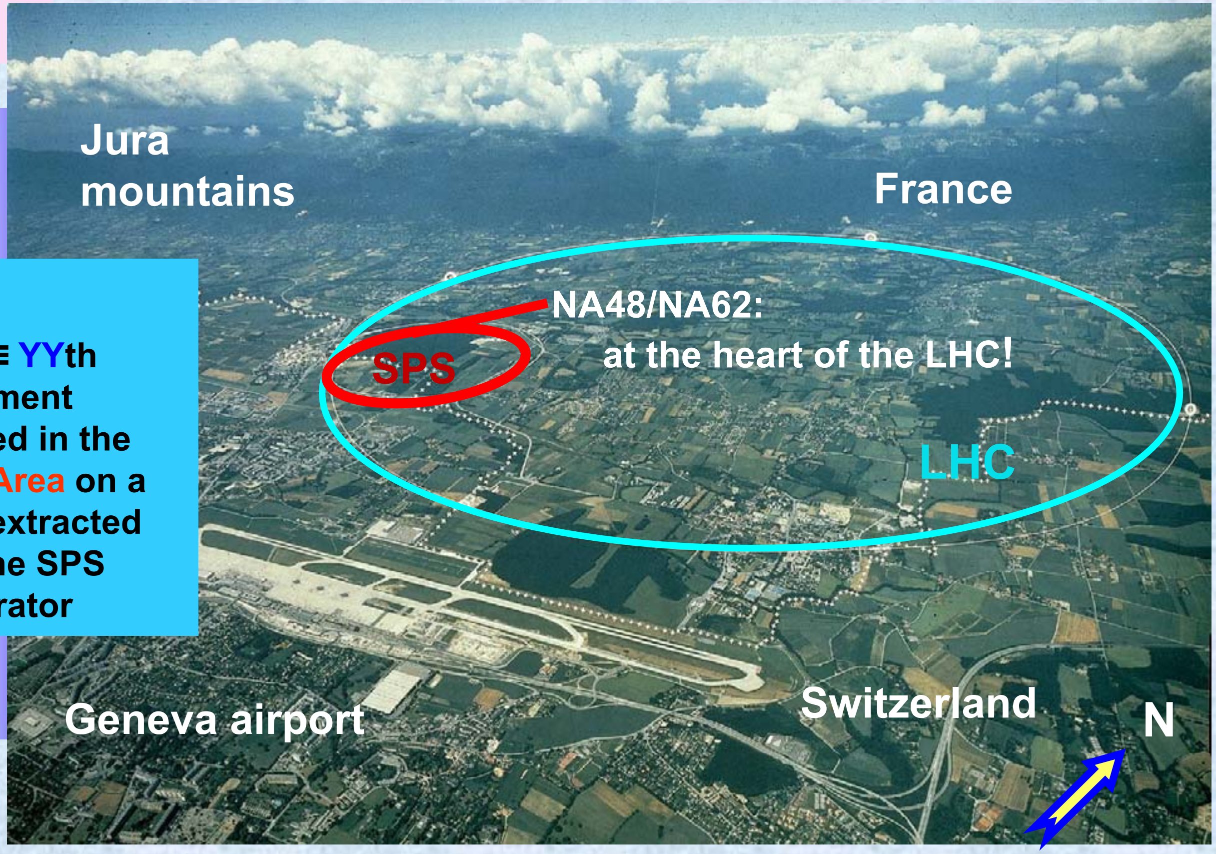
NA48

A fixed target experiment at the CERN SPS dedicated to the study of CP violation and rare decays in the Kaon sector



Note:

NAYY ≡ YYth experiment installed in the North Area on a beam extracted from the SPS accelerator



NA48: history……

NA48 (1997-2001)

➔ Direct CP violation in neutral kaon decays
Re(ε'/ε) = $(14.7 \pm 2.2) \times 10^{-4}$

➔ Measurement of CP violation parameter $|\eta_{+-}|$

NA48/1 (2002)

➔ Rare K_S decays

- BR ($K_S \rightarrow \pi^0 e^+ e^-$) = $(5.8^{+2.8}_{-2.3} \pm 0.8) \times 10^{-9}$
- BR ($K_S \rightarrow \pi^0 \mu^+ \mu^-$) = $(2.8^{+1.5}_{-1.2} \pm 0.2) \times 10^{-9}$

(not presented here….)

NA48/2 (2003-2004)

➔ Search for direct CP violation in $K^{\pm} \rightarrow 3\pi$ decays
Final result

and many other rare decay results!

Data taking periods

Year	Run
1997	ε'/ε run $K_L + K_S$
1998	ε'/ε run $K_L + K_S$
1999	ε'/ε run $K_L + K_S$; K_S Hi. Int.
2000	K_L only; K_S High Intensity; NO Spectrometer
2001	ε'/ε run $K_L + K_S$; K_S High Int.
2002	K_S High Intensity
2003	$K^{\pm}$ High Intensity
2004	$K^{\pm}$ High Intensity

The NA48 detector

Main detector components:

- Magnetic spectrometer (4 DCHs):
  4 views/DCH: redundancy ⇒ efficiency

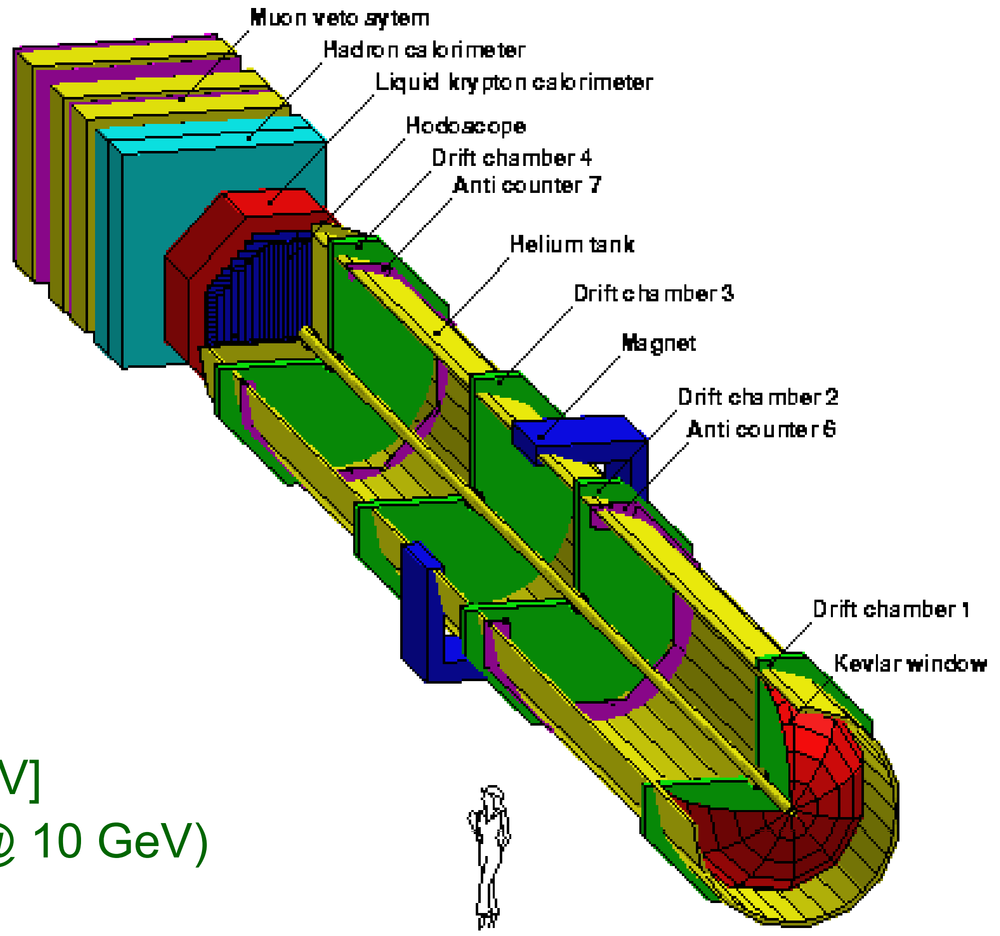
  $\sigma(p)/p = 1.02\% + 0.044\%\ p$ [GeV/c]
  $\sigma_{x,y} \sim 90\ \mu m$

- Hodoscope: fast trigger and precise time measurement (150ps)

- Liquid Krypton e.m. calorimeter:
  High granularity, quasi−homogeneous

  $\sigma(E)/E = 3.2\%/\sqrt{E} + 9\%/E + 0.42\%$ [GeV]
  $\sigma_x = \sigma_y = 0.42/\sqrt{E} + 0.6$ mm (1.5 mm @ 10 GeV)

- Hadron calorimeter, photon vetos, muon veto counters



CP Violation in Neutral Kaon decays (NA48)

1) ε'/ε Direct CP violation

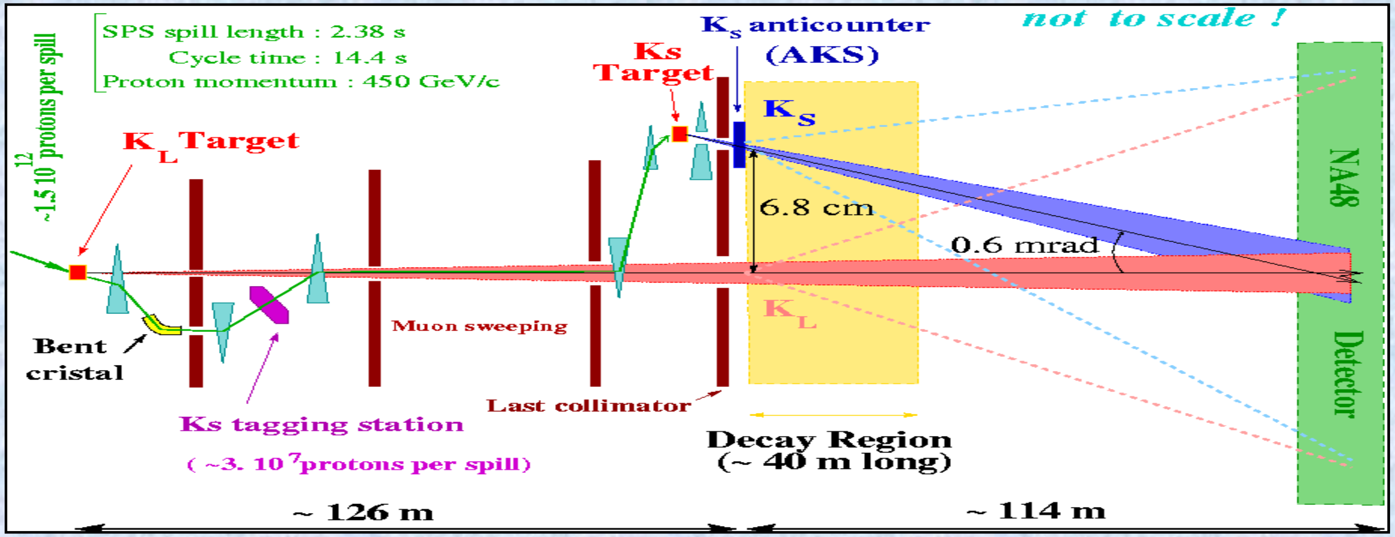
2) $|\eta_{+-}|$ The CP violation parameter

1) ε'/ε Direct CP violation in $K^0 \to 2\pi$ decays

ε'/ε **derived from the double ratio**

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

Experiment designed to exploit cancellations of systematic effects

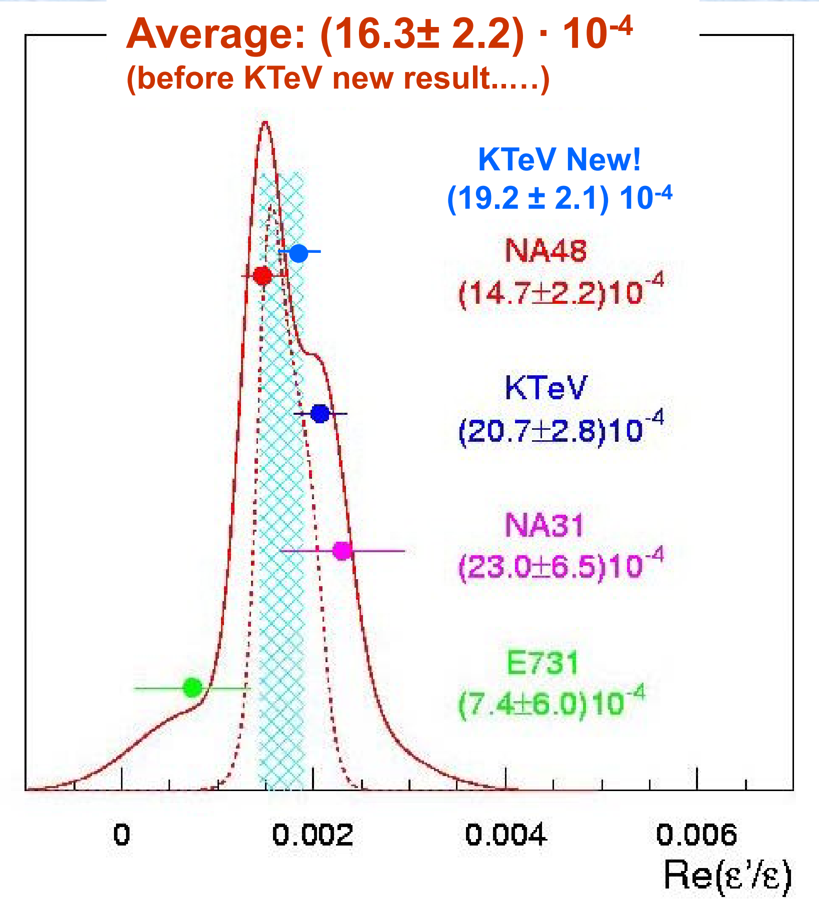


Simultaneous K beams:
- split same proton beam ($\sim 10^{12}$ ppp)
- convergent K_L-K_S beams
- K_S from protons on near target
- K_S identification via proton tagging

- 4 decay modes collected simultaneously
- Same decay region for all modes
- K_L events weighted by a function of their lifetime
- K_S events weighted by K_L/K_S intensity ratio
- K_S decays distinguished from K_L events by time coincidence of decay time and time of protons on the **tagger** (same for $\pi^+\pi^-$ and $\pi^0\pi^0$ decays)
- Analysis performed in 20 bins of kaon energy

ε'/ε Result

$Re(\varepsilon'/\varepsilon) = (14.7 \pm 2.2) \times 10^{-4}$

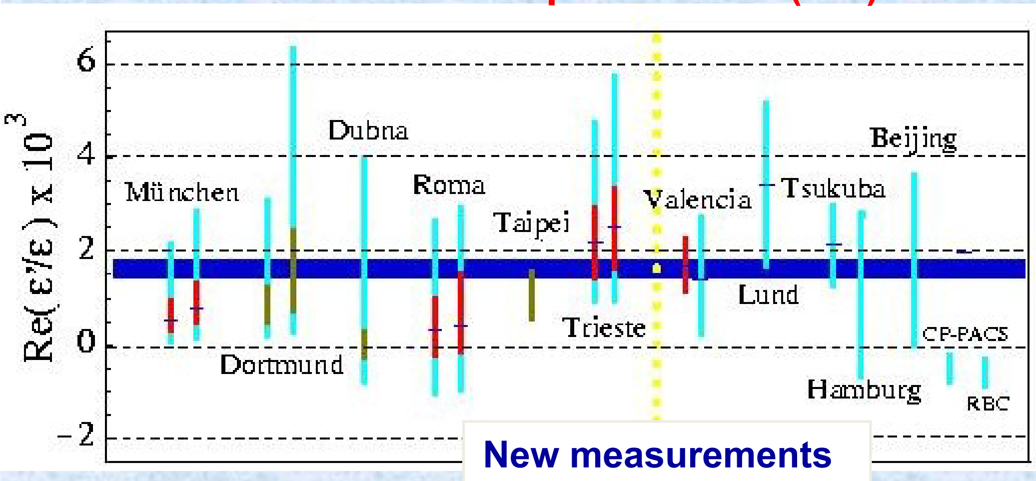


Observation of Direct CP Violation in $K^0 \rightarrow 2\pi$ decays

↓

Tiny particle - antiparticle asimmetry

Theoretical predictions (SM)



2) η_{+-} Direct and Indirect CPV in $K_L \to \pi^+\pi^-$ decays

The CPV parameter η_{+-} : a fundamental observable of CP violation

$$\eta_{+-} = \varepsilon + \varepsilon' = \frac{A(K_L \to \pi^+\pi^-)}{A(K_S \to \pi^+\pi^-)}$$

CPV decay

Indirect CPV — Direct CPV

CP = –1 CP = +1

$K_L \sim K_2 + \varepsilon K_1$

$K_S \sim K_1 + \varepsilon K_2$

$CP(\pi^+\pi^-) = +1$

Experimental Method:

- Measure the ratio of the decay rates → $\dfrac{\Gamma(K_L \to \pi^+\pi^-)}{\Gamma(K_L \to \pi^\pm e^\mp \nu)}$
- Compute → $BR(K_L \to \pi^+\pi^-) = \dfrac{\Gamma(K_L \to \pi^+\pi^-)}{\Gamma(K_L \to \pi^\pm e^\mp \nu)} BR(K_L \to \pi^\pm e^\mp \nu)$
- Extract → $|\eta_{+-}| = \sqrt{\dfrac{\Gamma(K_L \to \pi^+\pi^-)}{\Gamma(K_S \to \pi^+\pi^-)}} = \sqrt{\dfrac{BR(K_L \to \pi^+\pi^-)}{BR(K_S \to \pi^+\pi^-)} \cdot \dfrac{\tau_{KS}}{\tau_{KL}}}$

Using the best single K_S (NA48'02) and K_L (KLOE'06) lifetime measurements and $BR(K_L \to \pi e \nu)$ (NA48'04 + KTeV'04, KLOE'06) and $BR(K_S \to \pi^+\pi^-)$ (KLOE'06)

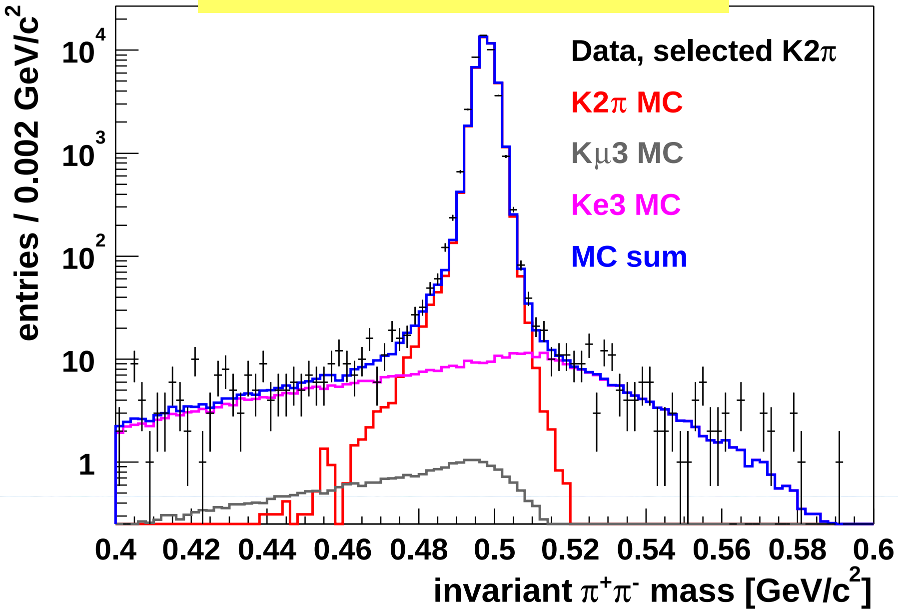
$\Gamma_{K2\pi}/\Gamma_{Ke3}$ event selection

Dedicated 2-day run in 1999 with a pure low intensity K_L beam: ~80 million 2-track events

$K_L \to \pi^+\pi^-$

- CP violating process:
need to suppress dominant background (K_{e3}, $K_{\mu3}$, $K_L \to \pi^+\pi^-\pi^0$) by 4-5 orders of magnitude
- Acceptance = $(58.26 \pm 0.04)\%$
- Small background ~0.5%
- Data well described by MC

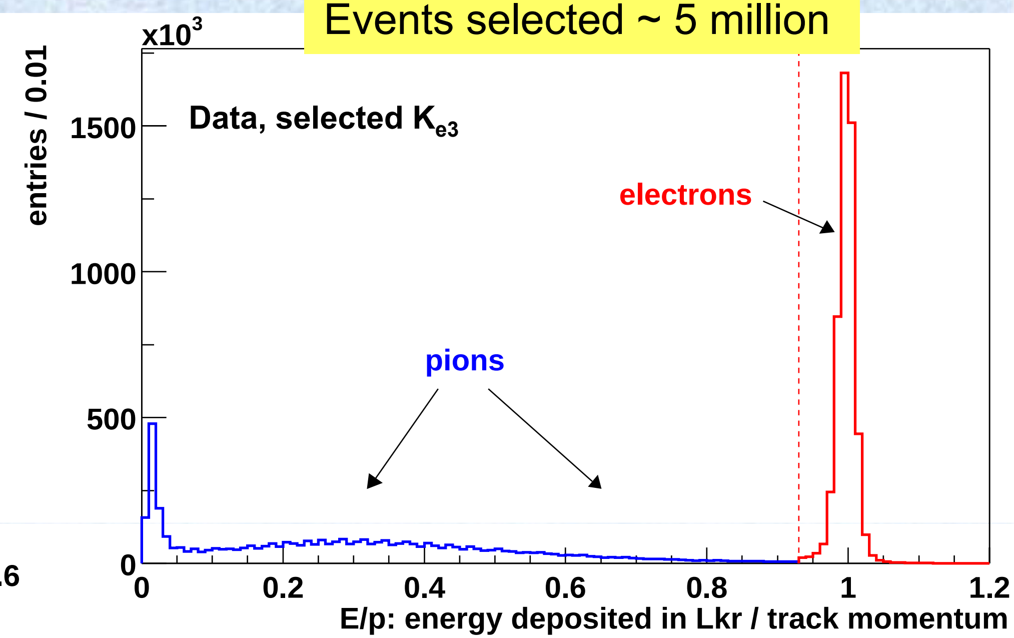
Events selected ~ 47000



$K_L \to \pi e \nu$

- Select K_{e3} decays by **e-ID** using the ratio **E/p≈1** (energy in electromagnetic calorimeter over track momentum)
- Acceptance = $(29.86 \pm 0.02)\%$
- Small background ~ 0.5%

Events selected ~ 5 million



Result on $|\eta_{+-}|$

➢ **The directly measured value:**

$$R = \Gamma(K_L\to\pi^+\pi^-) / \Gamma(K_L\to\pi e\nu) = (4.835 \pm 0.022_{stat.} \pm 0.016_{syst.}) \times 10^{-3}$$

➢ **Branching fraction:**

$$BR(K_L\to\pi^+\pi^-) = (1.941 \pm 0.019) \times 10^{-3}$$

Radiative corrections:

- Includes $\pi^+\pi^-\gamma$ IB component
- DE component (CP conserving) is subtracted

Corrections and systematics on R

Uncertainty source	Correction	Uncertainty
Particle ID	+1.34%	0.05%
$K_{2\pi}$ background	–0.49%	0.03%
Muon ID	+0.48%	0.18%
Trigger	–1.29%	0.11%
Energy spectrum		0.20%
Radiative corrections		0.10%
MC statistics		0.10%
Total	**+0.04%**	**0.33%**

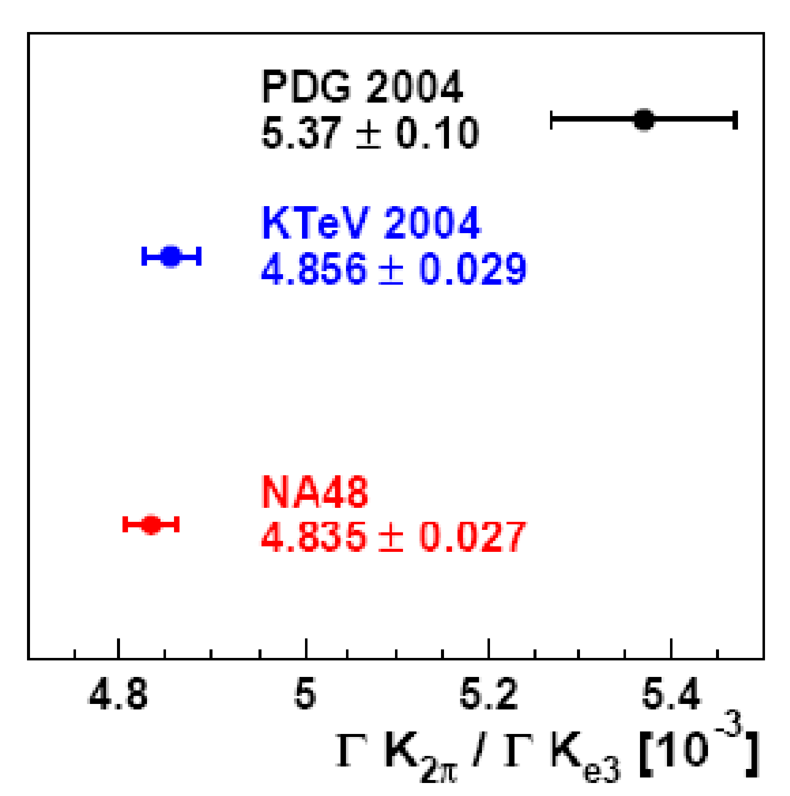
➢ **The CP violation parameter:**

$$|\eta_{+-}| = \sqrt{\frac{BR(K_L\to\pi^+\pi^-)}{BR(K_S\to\pi^+\pi^-)} \cdot \frac{\tau_{K_S}}{\tau_{K_l}}} = (2.223 \pm 0.012) \times 10^{-3}$$

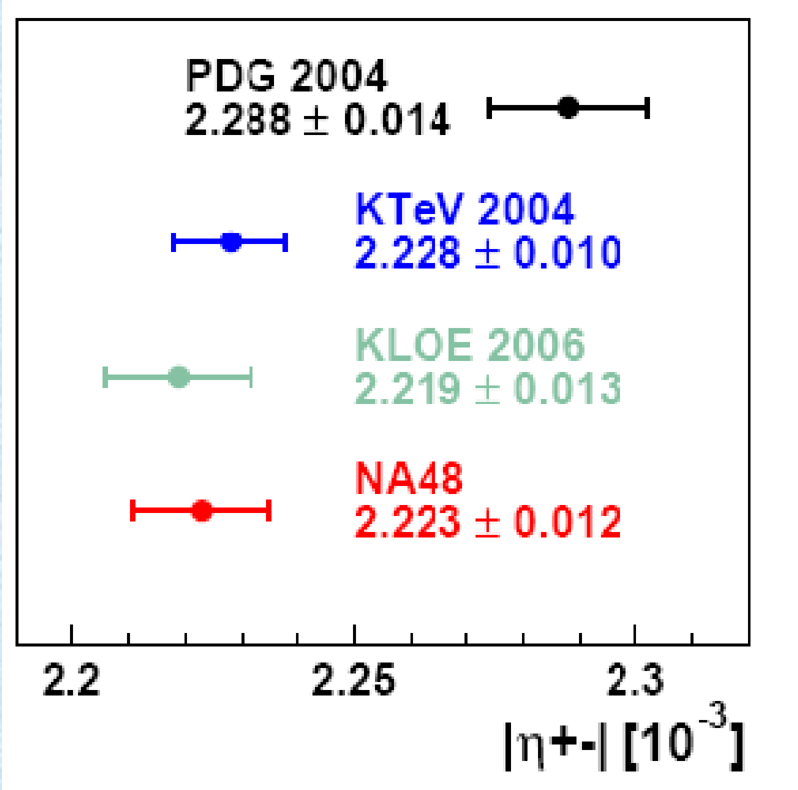
Published in Phys. Lett. B645 (2007) 26

$|\eta_{+-}|$ Comparison to world data

$\Gamma_{K2\pi}/\Gamma_{Ke3}$



$|\eta_{+-}|$



- **Good agreement between NA48, KTeV and KLOE results**
- **Recent measurements led to revision of the Particle Data Group average** (PDG 2008 : $|\eta_{+-}|$ = 2.233 ± 0.012)

Direct CP Violation in $K^{\pm} \rightarrow \pi^{\pm}\pi^{+}\pi^{-}$ and $K^{\pm} \rightarrow \pi^{\pm}\pi^{0}\pi^{0}$ decays

(NA48/2)

CP violation in $K^{\pm} \to 3\pi$ decays

- Only direct CPV in $K^{\pm}$ possible – mixing is not allowed
- Potentially large statistics:

BR ($K^{\pm} \to \pi^{\pm}\pi^{+}\pi^{-}$) = 5.57% **BR ($K^{\pm} \to \pi^{\pm}\pi^{0}\pi^{0}$) = 1.73%**

- Simple selection
- Low background

Method:

- No absolute kaon flux measurement is required
- Compare only Dalitz plot shapes between K^{+}/K^{-}

The CP violation parameter A_g

Kinematics:

$s_i = (P_K - P_{\pi i})^2$, i=1,2,3 (3=odd π)

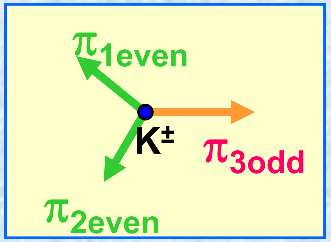
$s_0 = (s_1+s_2+s_3)/3$

$u = (s_3 - s_0)/m_\pi^2$

$v = (s_2 - s_1)/m_\pi^2$

Matrix element:

$|M(u,v)|^2 \sim 1 + gu + hu^2 + kv^2 + \ldots$



Kaon rest frame:

$u = 2m_K \cdot (m_K/3 - E_{odd})/m_\pi^2$

$v = 2m_K \cdot (E_1 - E_2)/m_\pi^2$

$K^\pm \to \pi^\pm\pi^+\pi^-$ NA48/2 Slopes:

g = (-21.134 ± 0.017)%

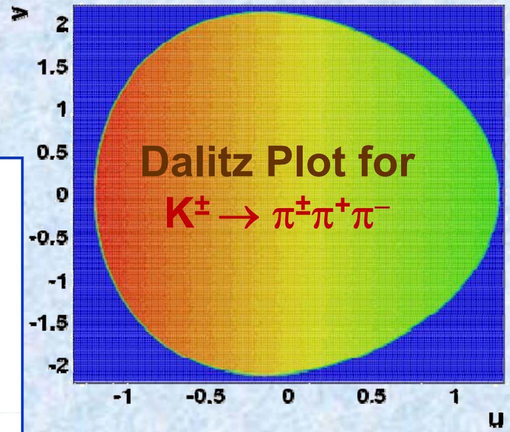
h = (1.848 ± 0.040)%

k = (–0.463 ± 0.014)%

Phys. Lett. B649 (2007) 349-358

$K^\pm \to \pi^\pm\pi^0\pi^0$ PDG value:

g = (62.6 ± 0.7)%



Direct CP-violating quantity: the slope asymmetry

$A_g = (g_+ - g_-)/(g_+ + g_-) = \Delta g/2g$

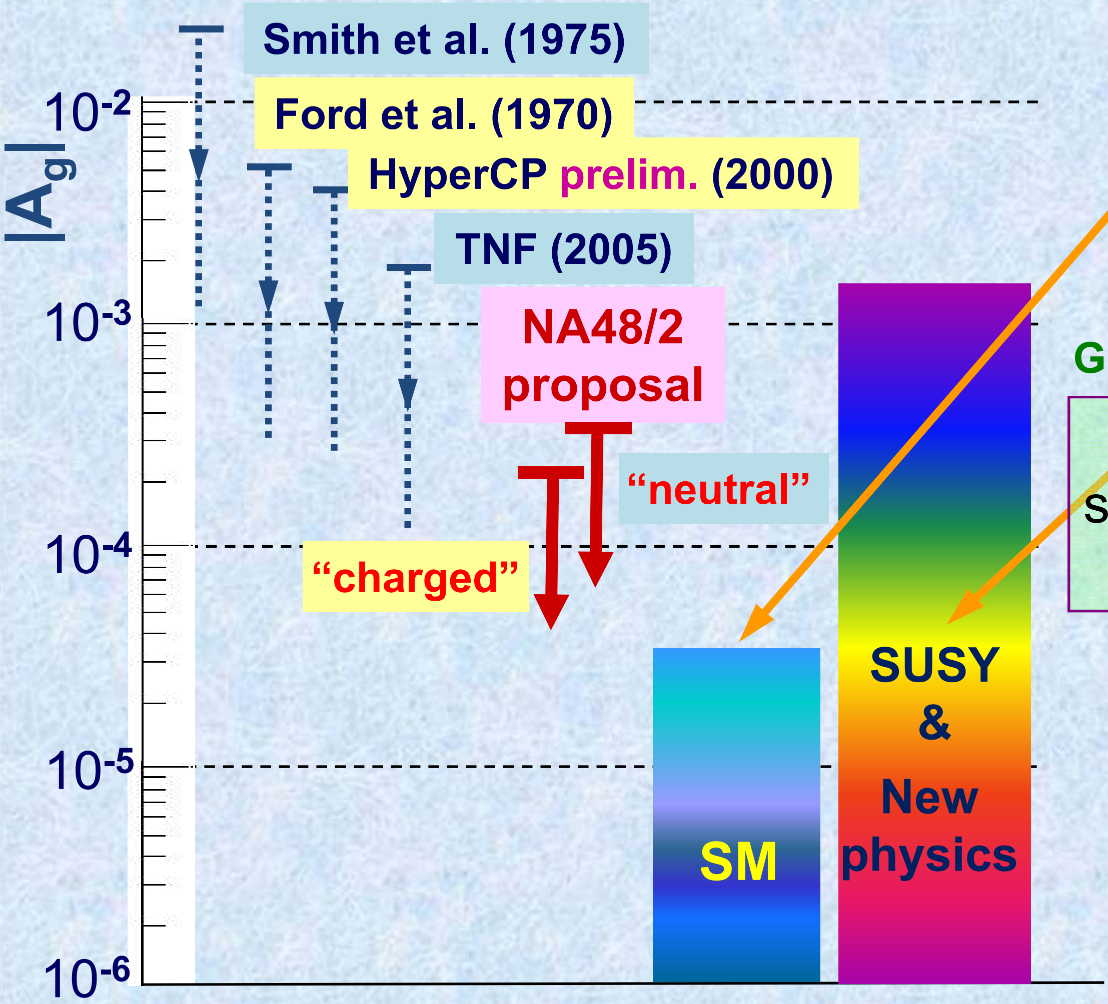
SM predictions: $|A_g|$: 10^{-5} - 10^{-6}

If $A_g \sim 10^{-4} \Rightarrow$ ***New Physics !***

If $A_g \neq 0 \Rightarrow$ ***Direct CP Violation***

Experiments & Theory

Experimental precisions before NA48/2:
[$\delta A_g \sim 10^{-3}$, dominated by systematics]



E. Gámiz et al., JHEP 10 (2003) 42

SM estimate (NLO ChPT):

$$A_g^c = (-1.4 \pm 1.2) \times 10^{-5}$$
$$A_g^n = (1.1 \pm 0.7) \times 10^{-5}$$

G. D'Ambrosio et al., PLB480 (2000) 164

Models **beyond the SM** predict substantial enhancement partially within the reach of NA48/2

Asymmetry of integrated decay rates is strongly suppressed

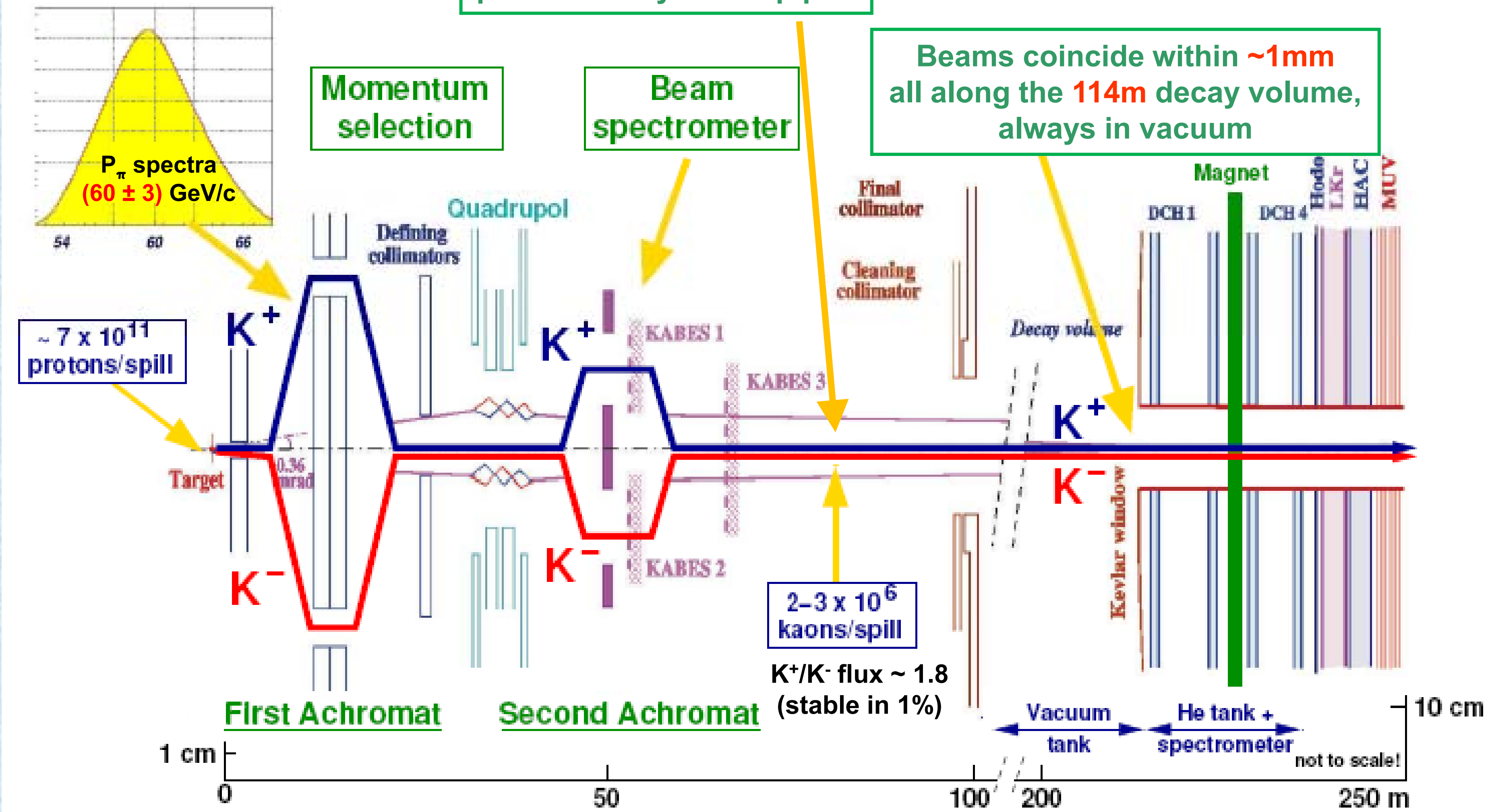
NA48/2 Goal and method

- **Primary NA48/2 goal:**
  - Measure slope asymmetries in "charged" and "neutral" modes with high accuracy (few 10^{-4})
- **Strategy**
  - To measure a tiny asymmetry one must guarantee perfect charge symmetrization in the experimental setup and eliminate the remaining acceptance differences by a smart analysis technique
- **NA48/2 method:**
  - Two simultaneous K^+ and K^- beams, superimposed in space, with similar narrow momentum spectra
  - Equalise averaged K^+ and K^- acceptances by frequently alternating the polarities of the relevant magnets
  - Measure asymmetry exclusively considering slopes of ratios of normalized u distributions

The K^+/K^- simultaneous beam setup

SPS Spill Length : 4.8 s
Cycle Time : 16.8 s
Proton momentum : 400 GeV/c

20 MHz ($\pi/K \sim 12$) π decay products stay inside pipe



NA48/2 data taking completed

View of the NA48/2 beam line

2003 run: ~ 50 days
2004 run: ~ 60 days

Statistics:

$K^{\pm} \rightarrow \pi^{\pm} \pi^{+}\pi^{-}$: ~ 4×10^{9}
$K^{\pm} \rightarrow \pi^{\pm} \pi^{0}\pi^{0}$: ~ 1×10^{8}

Sensitivity to $K^{\pm}$ decays with branching ratios down to 10^{-9}

More than 200 TBytes recorded !

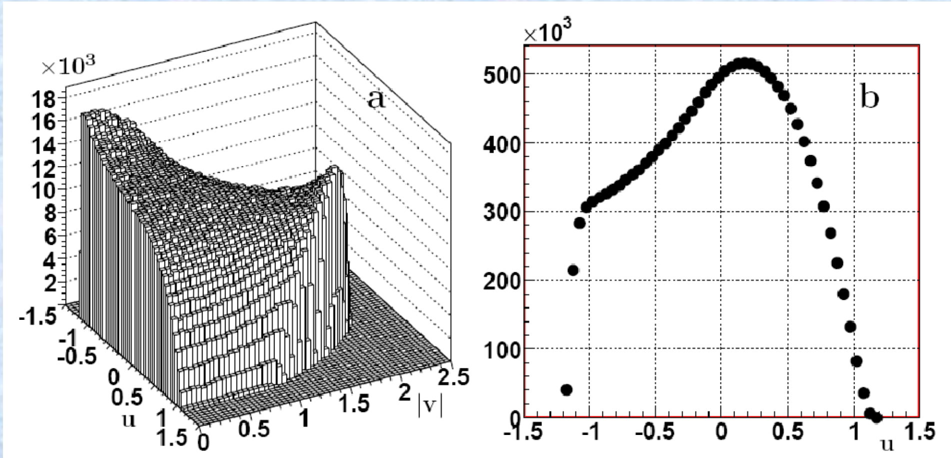
Method to extract A_g

- Build u projections of the Dalitz plot for K^+ and K^-: $N^+(u)$,$N^-(u)$
- Make the ratio of these two distributions: R(u)
- Fit a function to this ratio to extract Δg

  (This holds only if the acceptance for K^+ and K^- is the same)

$$R(u) = \frac{N^+(u)}{N^-(u)} \approx 1 + \frac{\Delta g \cdot u}{1 + gu + hu^2}$$

$K^\pm \to \pi^\pm \pi^+ \pi^-$



BUT!

There are experimental asymmetries that do not cancel in the simple ratio R(u)

To cancel the charge asymmetry in the detector and beam optics:

- → **Beam line (achromat) polarity (A) is reversed on weekly basis**
- → **Spectrometer magnet polarity (B) is reversed on few hours basis**

Acceptance cancellation

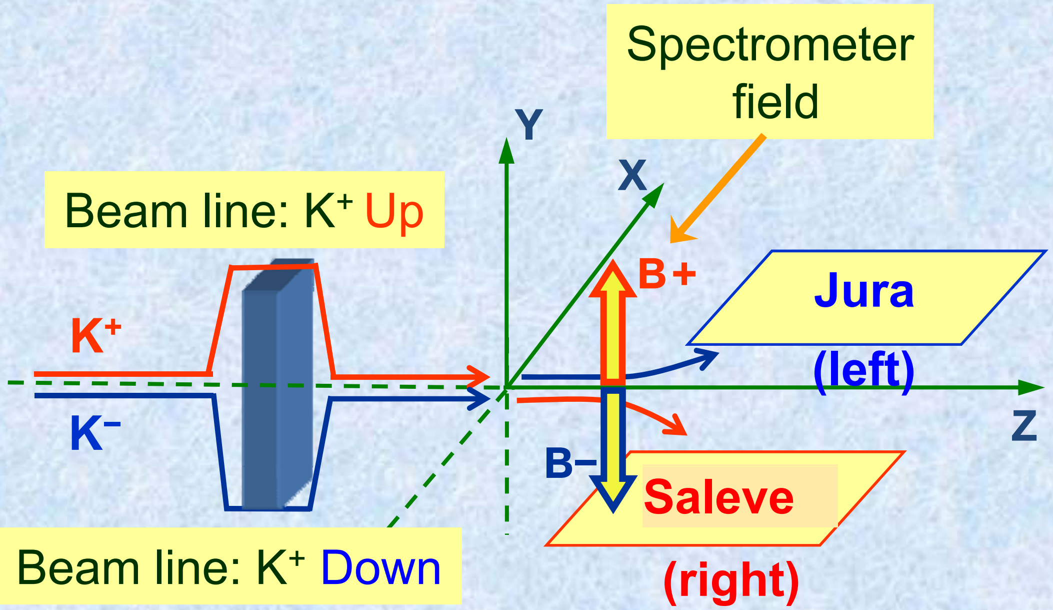
Detector left/right asymmetry cancels in 4 ratios of K^+/K^- U-spectra corresponding to the four possible combinations of the magnetic fields:

$$R_{US} = \frac{N(A+B+K+)}{N(A+B-K-)}$$

$$R_{UJ} = \frac{N(A+B-K+)}{N(A+B+K-)}$$

$$R_{DS} = \frac{N(A-B+K+)}{N(A-B-K-)}$$

$$R_{DJ} = \frac{N(A-B-K+)}{N(A-B+K-)}$$



Indexes correspond to: beam line polarity (U/D)
left/right direction of kaon deviation in spectrometer (J/S)

K samples in numerator and denominator illuminate the same parts of the detector

Quadruple Ratio

❖ **Use a quadruple ratio for maximum cancellation of systematic biases**

$$\mathbf{R_4} = R_{US} \cdot R_{UJ} \cdot R_{DS} \cdot R_{DJ}$$

⇨ Cancellation of global time instabilities + local beamline biases (K^+,K^- simultaneously recorded)

⇨ Cancellation of left-right detector asymmetries

⇨ Cancellation of effect of permanent stray fields (earth, vacuum tank magnetization)

❖ **Extract Δg by fitting the quadruple ratio:**

$$f(u) = n \cdot \left(1 + \frac{\Delta g u}{1 + g u + h u^2} \right)^4$$

❖ **Advantages:**

⇨ Result sensitive only to time variation of asymmetries in short time intervals (smaller than corresponding field alternating period)

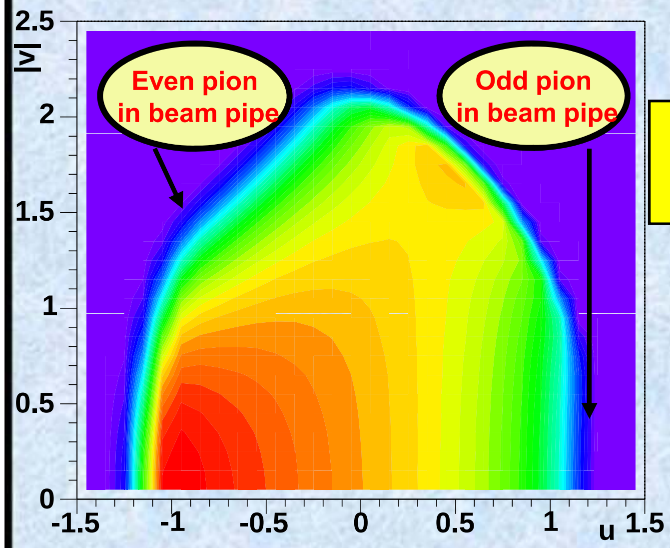
⇨ The method is independent of K^+/K^- flux ratio and relative sizes of the samples

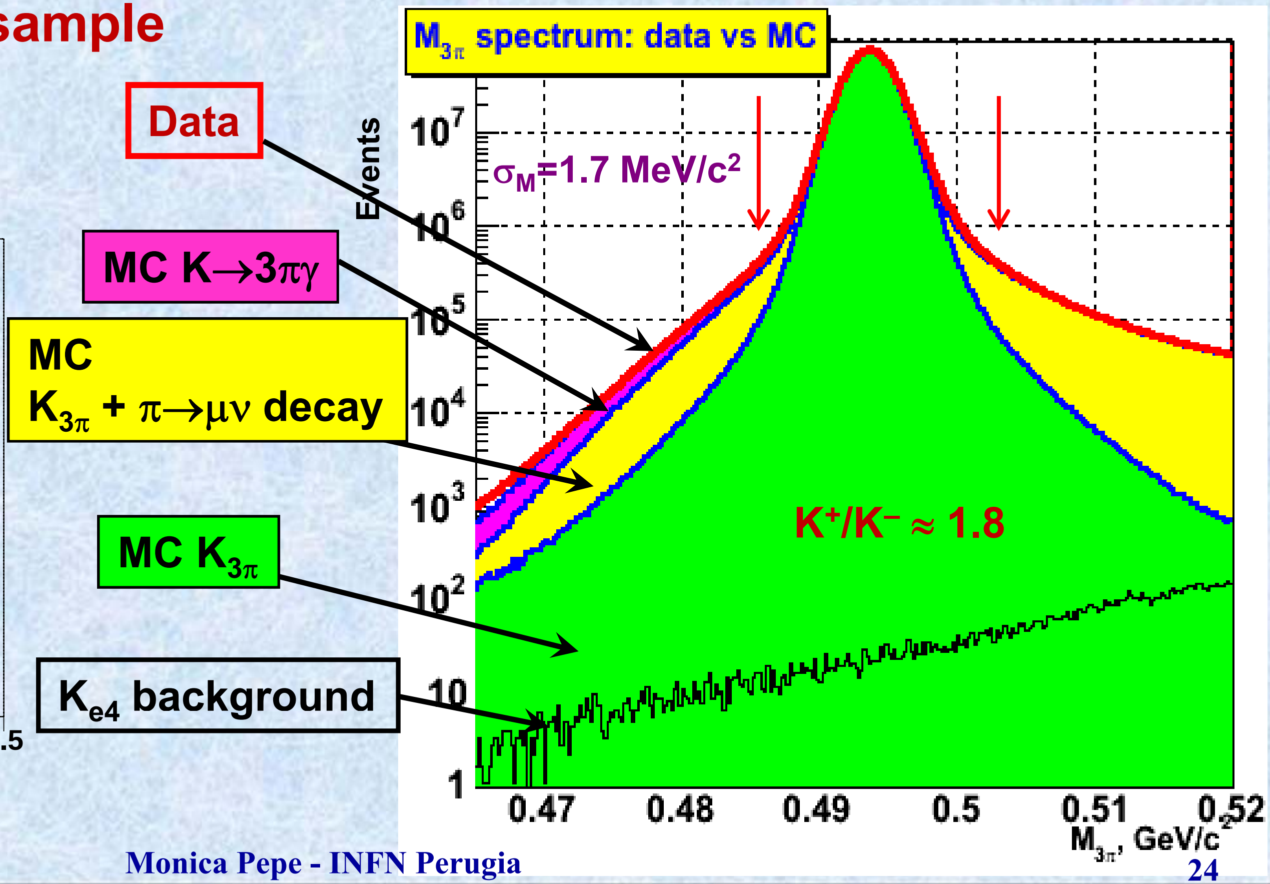
⇨ The analysis does not rely on a detailed MC to calculate acceptances

$K^{\pm}\to 3\pi^{\pm}$ event selection

- Trigger selection based on Hodoscope and Magnetic Spectrometer
- Offline reconstruction based on Magnetic Spectrometer only : event kinematics from track momenta and directions extrapolated to decay vertex
- Acceptance limited mostly by beam pipe through DCHs
- Negligible background

3.11×10^9 fully reconstructed events from 2003+2004 sample





$K^{\pm} \rightarrow 3\pi^{\pm}$ asymmetry: result

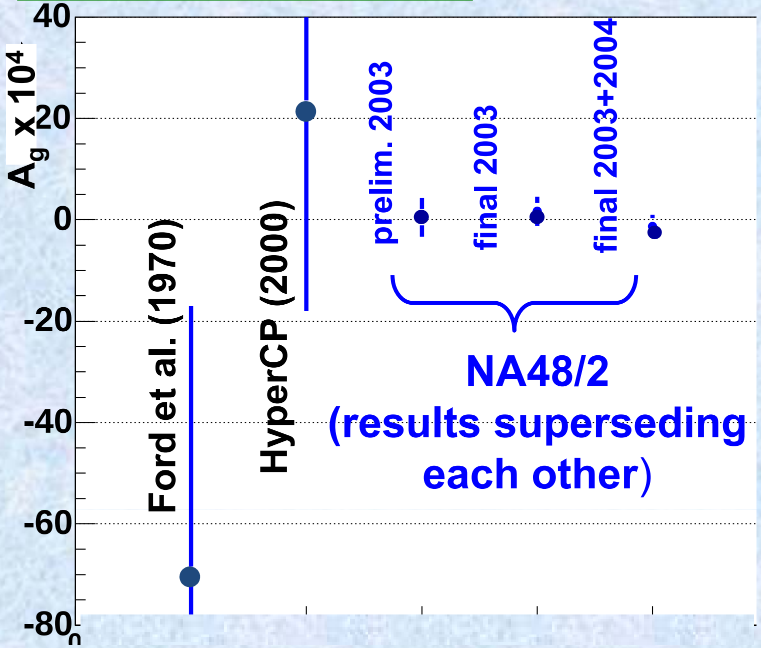
$\Delta g = (0.7 \pm 0.7_{stat} \pm 0.4_{trig} \pm 0.6_{syst}) \times 10^{-4}$
$= (0.6 \pm 0.9) \times 10^{-4}$

$A_g = (-1.5 \pm 1.5_{stat} \pm 0.9_{trig} \pm 1.3_{syst}) \times 10^{-4}$
$= (-1.5 \pm 2.2) \times 10^{-4}$

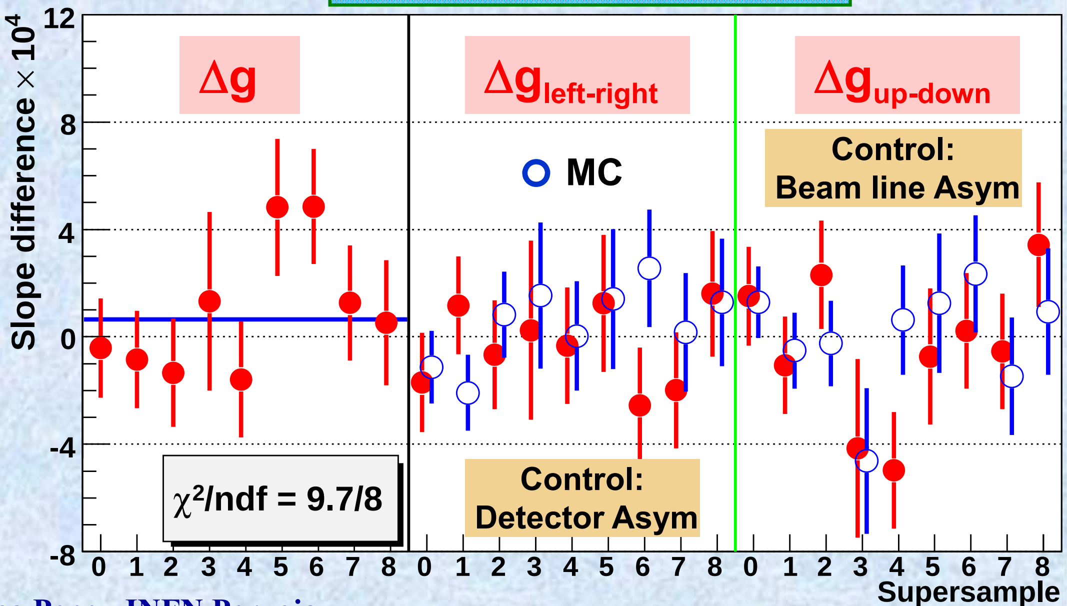
Published: Eur. Phys. J. C52 (2007) 875

- A factor ~20 better precision than previous measurements
- Uncertainties of statistical nature dominates
- Result compatible with SM
  No evidence for New Physics
- NA48/2 design goal reached.

Measurements of A_g

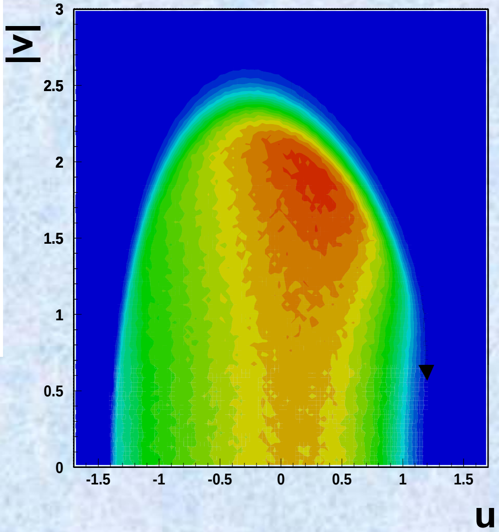


Time stability of results



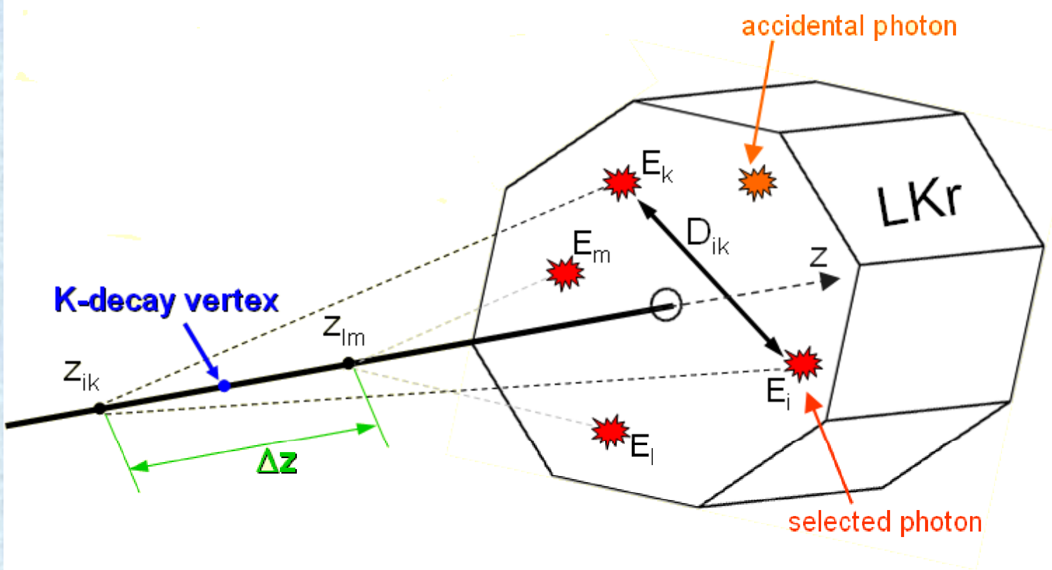
$K^\pm \to \pi^\pm\pi^0\pi^0$ event selection

- **Based on Charged Spectrometer and LKR El. Magn. Calorimeter**
- **Charge-symmetric procedure:**
  - **- no geometrical information from the $\pi^\pm$ track**
  - **- computation of u variable from the $\pi^0\pi^0$ invariant mass only**
- **Two $\pi^0 \to \gamma\gamma$ decays define $K^\pm$ decay vertex position**
  - **- $\pi^0\pi^0$ longitudinal vertex position in decay volume**

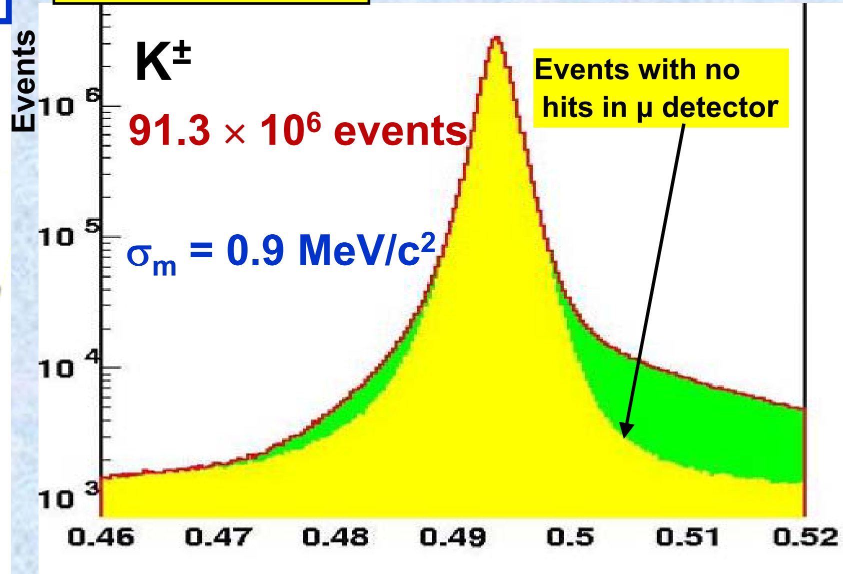


For each photon pair (i,k),(l,m) a decay vertex is reconstructed along the beam axis under the assumption of $\pi^0 \to \gamma\gamma$ decay

$$M(\pi^0)^2 = 2E_iE_k(1-\cos\alpha) \approx E_iE_k\,(D_{ik})^2/(Z_{ik})^2$$



$M_{3\pi}$ spectrum



$K^{\pm}\rightarrow\pi^{\pm}\pi^{0}\pi^{0}$ asymmetry: result

$$\Delta g^0 = (2.2 \pm 2.1_{stat} \pm 0.7_{syst}) \times 10^{-4} = (2.2 \pm 2.2) \times 10^{-4}$$

$$A_g^0 = (1.8 \pm 1.7_{stat} \pm 0.6_{syst}) \times 10^{-4} = (1.8 \pm 1.8) \times 10^{-4}$$

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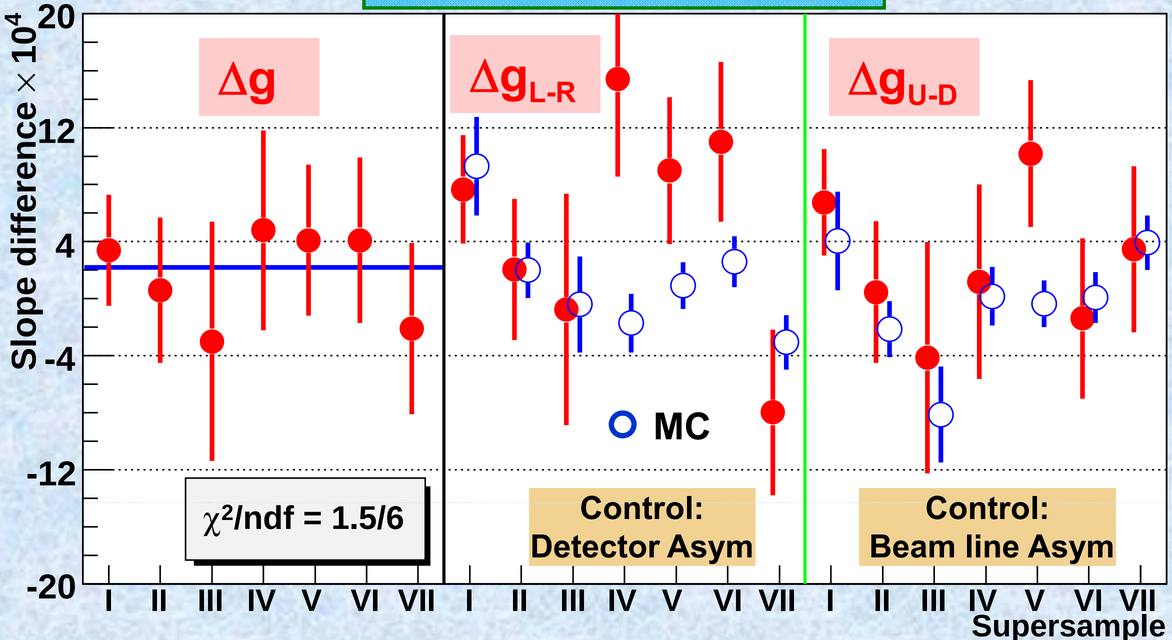
- Statistical precision in A_g^0 similar to $K^{\pm} \rightarrow \pi^{\pm}\pi^{+}\pi^{-}$ mode
- Ratio of charged to neutral event statistics $N^{\pm}/N^0 \sim 34$
- Ratio of slopes $|g^{\pm}/g^0| \sim 0.34$
- Final result consistent with Standard Model predictions

Time stability of results



- 7 super-samples give consistent results
- Detector and beam line asymmetry effects at a few 10^{-4} level, reproduced by MC

Conclusions

Over 10 years, the NA48 experiment at CERN has carried out an extensive physics programme devoted to the study of CP violation (and rare decays) in both neutral and charged Kaon sectors

NA48:

- Observation of Direct CP Violation in $K^0 \rightarrow 2\pi$ decays

  $Re(\varepsilon'/\varepsilon) = (14.7 \pm 2.2) \times 10^{-4}$

- Precise $|\eta_{+-}|$ measurement (0.5% accuracy)

  $|\eta_{+-}| = (2.223 \pm 0.012) \times 10^{-3}$

→ in agreement with recent KTeV and KLOE results, PDG average has been revised

NA48/2:

- Search for direct CP violating charge asymmetry in $K^\pm \rightarrow 3\pi$ decays

  $A_g = (-1.5 \pm 2.2) \times 10^{-4}$ $K^\pm \rightarrow \pi^\pm \pi^+ \pi^-$

  $A_g = (1.8 \pm 1.8) \times 10^{-4}$ $K^\pm \rightarrow \pi^\pm \pi^0 \pi^0$

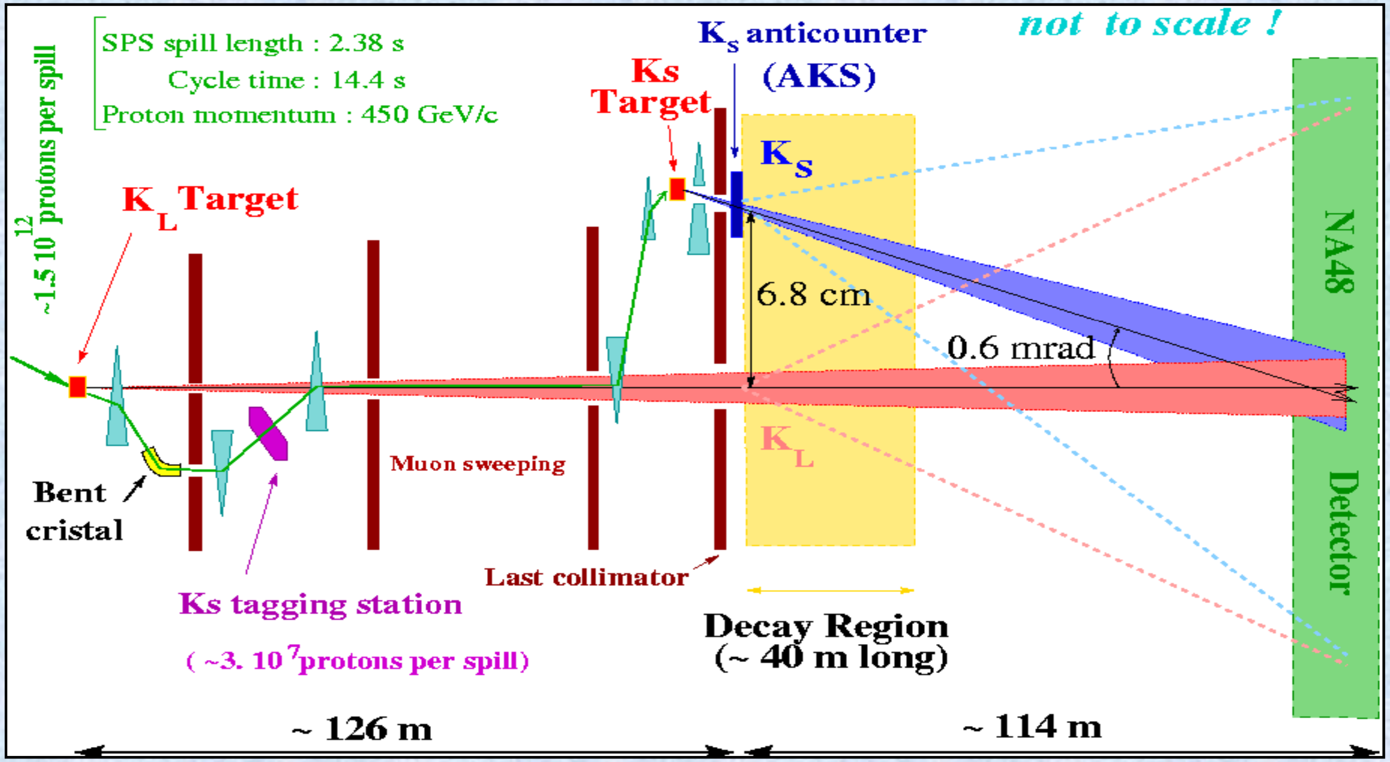
  No evidence of direct CPV at the level of 2×10^{-4}

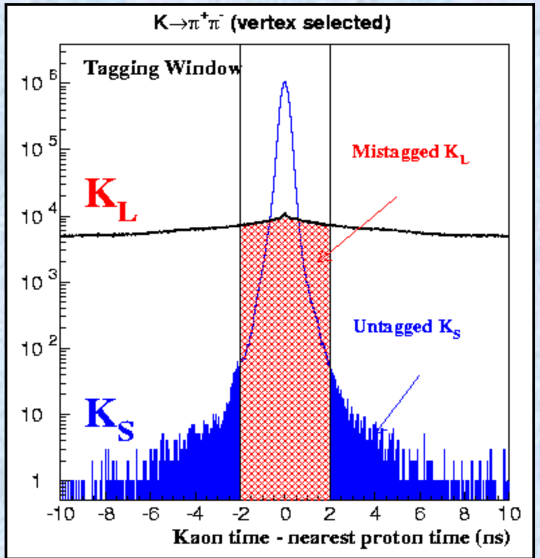
→ order of magnitude improvement in precision

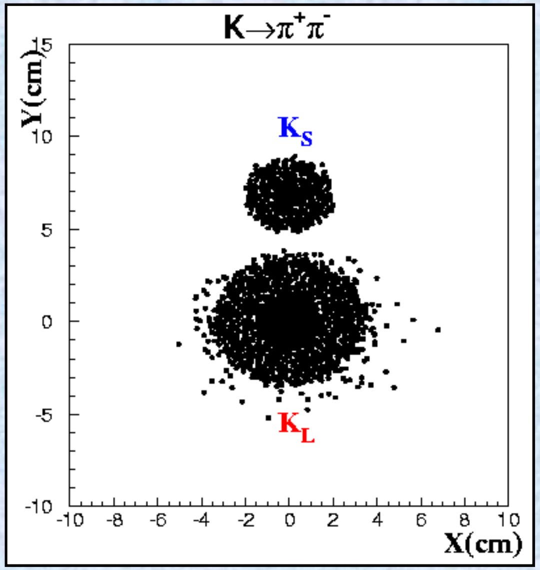
→ results in agreement with the SM expectation

SPARE SLIDES

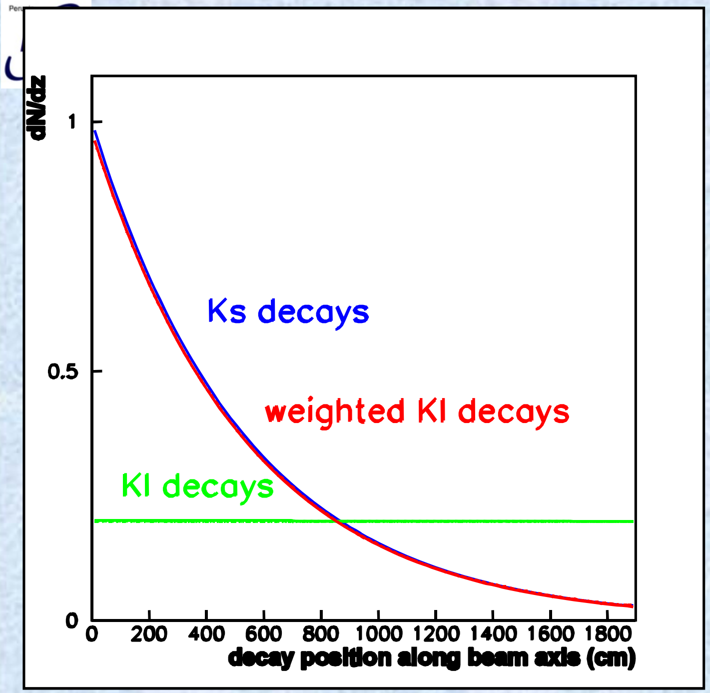
⟹

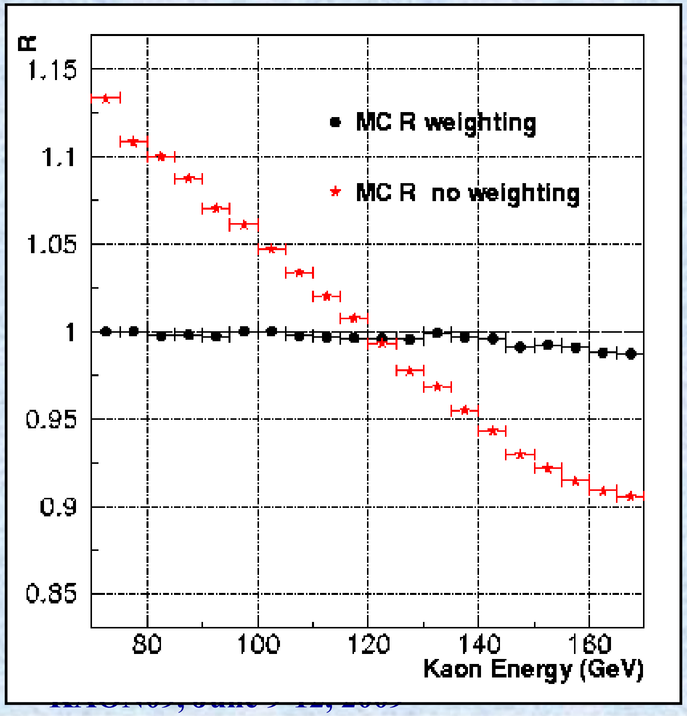

SPS spill length : 2.38 s
Cycle time : 14.4 s
Proton momentum : 450 GeV/c
$\sim 1.5\ 10^{12}$ protons per spill
K_L Target
Ks Target
K_S anticounter
(AKS)
not to scale !
K_S
K_L
6.8 cm
0.6 mrad
NA48
Detector
Bent cristal
Muon sweeping
Last collimator
Ks tagging station
(~3. 10^7 protons per spill)
Decay Region
(~ 40 m long)
~ 126 m
~ 114 m

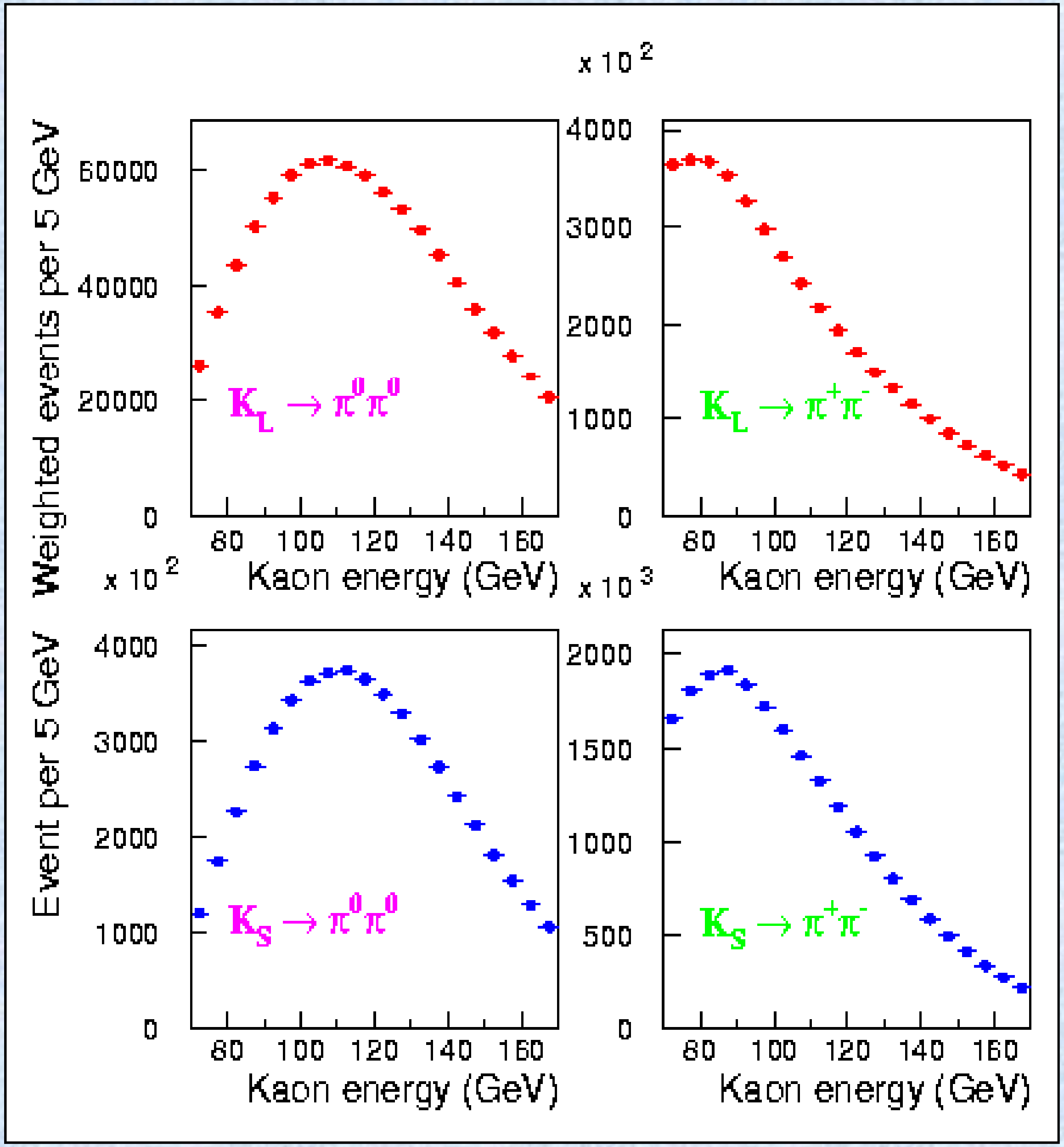

$K\to\pi^+\pi^-$ (vertex selected)
Tagging Window
Mistagged K_L
Untagged K_S
K_L
K_S
Kaon time - nearest proton time (ns)


$K\to\pi^+\pi^-$
Y(cm)
X(cm)
K_S
K_L

Acceptance for weighted K_S and K_L







Results

	98+99	2001
$\Delta(R)$ (x 10^{-4})	35.9 ± 12.6	35.0 ± 11.0

Contributions to corrections and syst: (x 10^{-4})

	98+99	2001
$\pi^+\pi^-$ trig. Ineff.	-3.6 ± 5.2.0	+5.2 ± 3.6
$\pi^0\pi^0$ bkg	-5.9 ± 2.0	-5.6 ± 2.0
$\pi^+\pi^-$ bkg	+16.9 ± 3.0	+14.2 ± 3.0
Beam scattering	-9.6 ± 2.0	-8.8 ± 2.0
Accidental Tagg	+8.3 ± 3.4	+6.9 ± 2.8 (stat)
Tagging ineff	-- ± 3.0	-- ± 3.0
Accept. stat.	+26.7 ± 4.1	+21.9 ± 3.5 (stat)
Accept. syst.	± 4.0	± 4.0

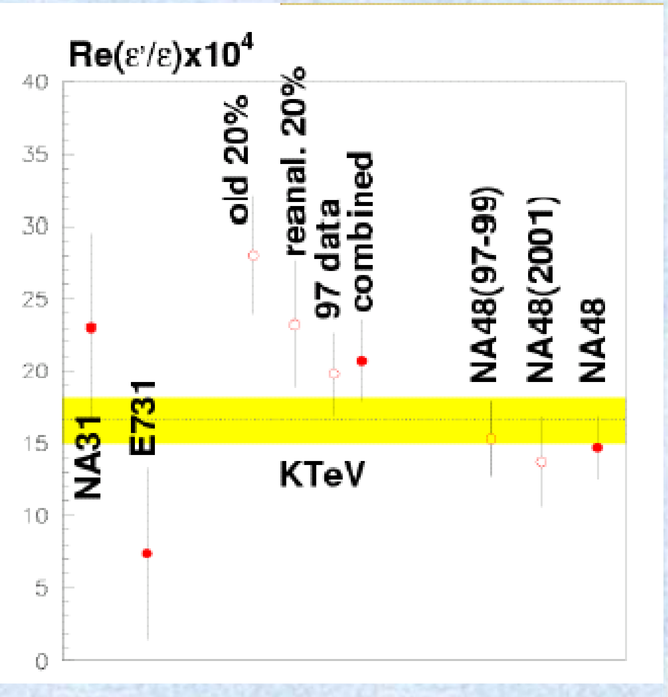
In 97: Syst. Error on $\Delta(R)$ ± 35

(trigg $\pi^+\pi^-$, reconstr $\pi^0\pi^0$, $\Delta\alpha_{LS}$, accidentals)

NA48 (97,98-99,2001)	(14.7 ± 2.2) x 10^{-4}
KTEV (96, 97)	(20.7 ± 2.8) x 10^{-4}
KTEV (new)	(19.2 ± 2.1) x 10^{-4}

Statistics (x 10^6)

	97	98+99	2001
$K_L \to \pi^0\pi^0$:	0.49	3.3	1.5
$K_S \to \pi^0\pi^0$:	0.98	5.2	2.2
$K_L \to \pi^+\pi^-$:	1.1	14.5	7.1
$K_S \to \pi^+\pi^-$:	2.1	22.2	9.6

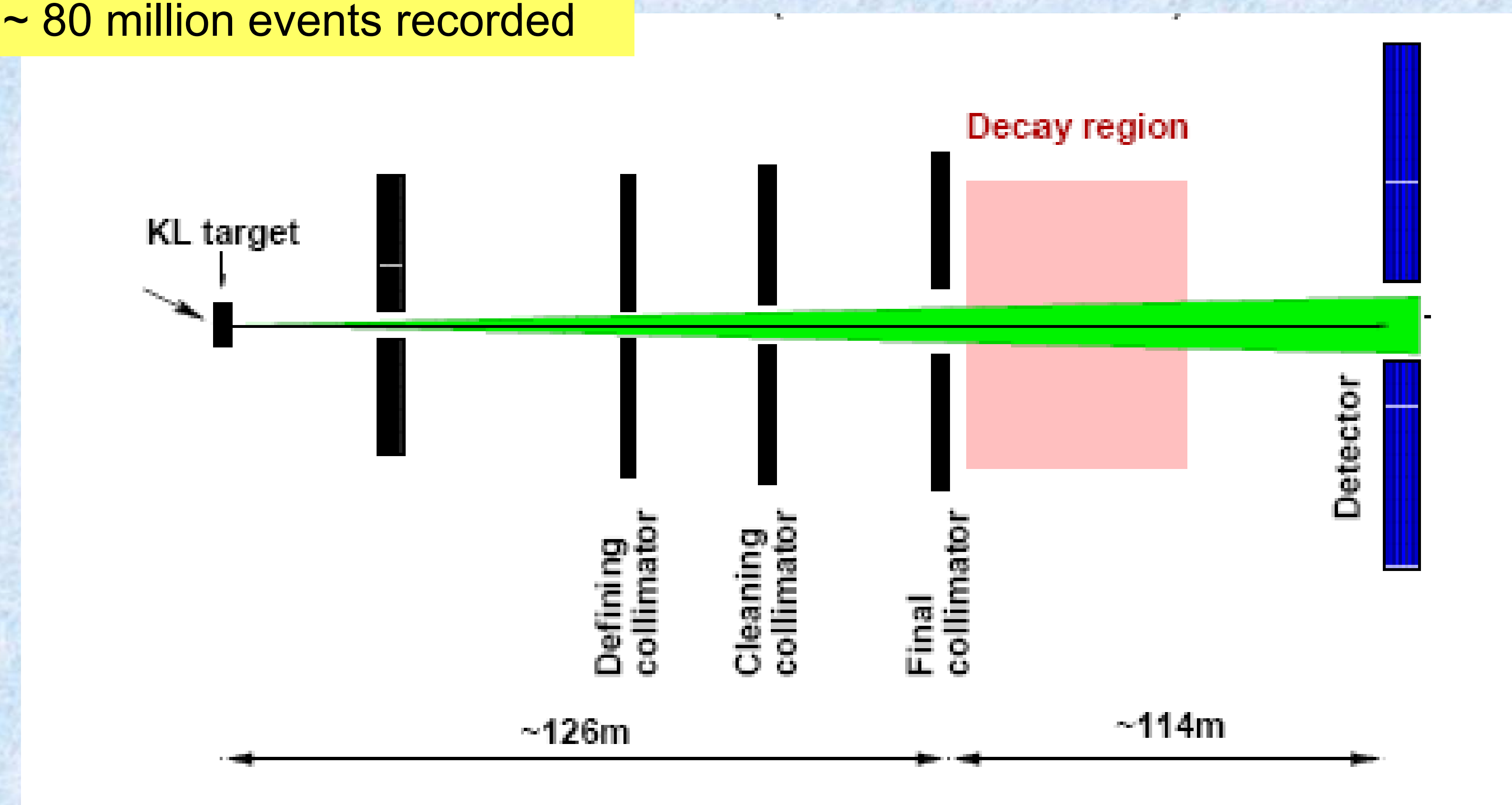


NA48 beam line for pure K_L beam

✓Special run (2 days in 1999) with pure K_L beam at low intensity.

✓Minimum bias trigger to select only events with 2 charged tracks

~ 80 million events recorded



$\Gamma_{K2\pi}/\Gamma_{Ke3}$ event selection

Basic two track selection :

1. Two tracks with opposite charge
2. CDA $\leq$ 3 cm
3. Vertex longitudinally between 8 m and 33 m from the final collimator
4. 15 GeV/c $\leq p_{trac} \leq$ 100 GeV/c

$\pi^+\pi^-$ selection :

1. $M_{\pi\pi}$ compatible with the K mass
2. p^2_{tK} <3x10^{-4} GeV/c^2
3. E/p < 0.93
4. No muons (to reject $K_{\mu3}$)

$\pi e\nu$ selection :

1. E/p > 0.93 → electron

$\Gamma(K \rightarrow 2\pi)/\Gamma(Ke3)$ systematics

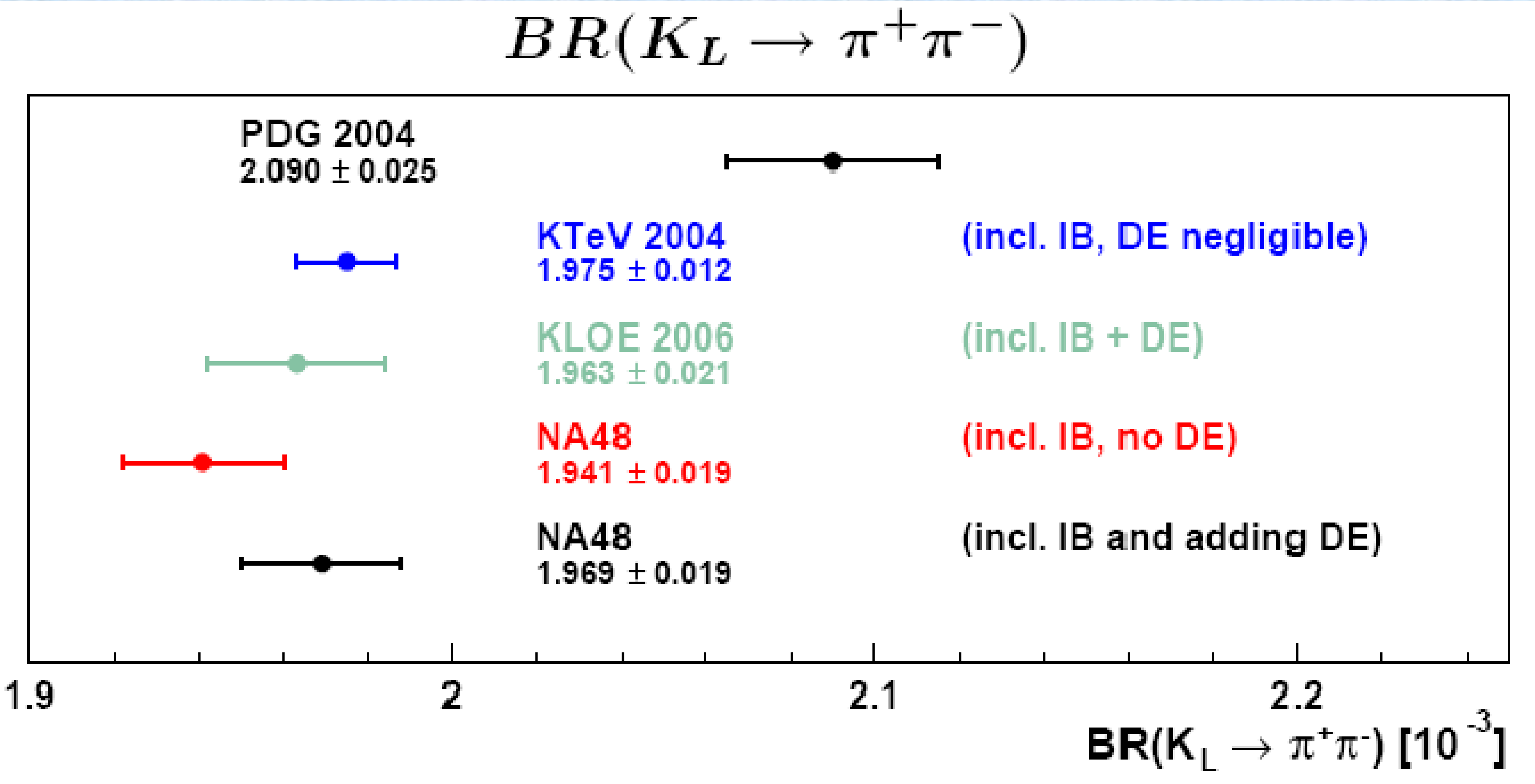
	Correction [%]	Uncertainty [%]
E/p cut	$+1.34$	0.05
Background in $K_{2\pi}$	-0.49	0.03
Muon cut	$+0.48$	0.18
Trigger efficiencies	-1.29	0.11
Energy spectrum	-	0.20
Radiative corrections	-	0.10
MC statistics	-	0.10
Total correction	$+0.04$	0.33

CP violation parameter η+ −

$$|\eta_{\pm}| = \sqrt{\frac{BR(K_L \to \pi^+\pi^-)}{BR(K_S \to \pi^+\pi^-)} \times \frac{\tau_{KS}}{\tau_{KL}}}$$

- External input: best single measurements
  - → K_S lifetime: $\tau_{KS} = (0.89598 \pm 0.00070) \times 10^{-10}$ s (NA48 '02);
  - → K_L lifetime: $\tau_{KL} = (5.084 \pm 0.023) \times 10^{-8}$ s (KLOE '06);
  - → $BR(K_L \to \pi e \nu) = 0.4022 \pm 0.0031$ (NA48 '04 + improved $K_L \to 3\pi^0$: KTeV, KLOE);
  - → $BR(K_S \to \pi^+\pi^-) = 0.69196 \pm 0.00051$ (KLOE '06).

η_{+-} Comparison of results

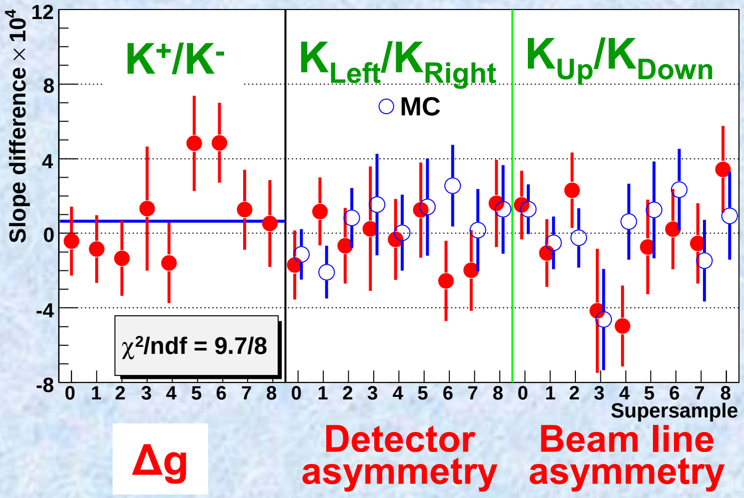


For comparison it is important to point out the treatment of radiative decays (IB and DE)

$K^{\pm} \rightarrow \pi^{\pm}\pi^{+}\pi^{-}$: A_g final result (2003+2004)

$\Delta g = (0.7 \pm 0.7_{stat.} \pm 0.4_{stat.\,(trig.)} \pm 0.6_{syst.}) \times 10^{-4}$

Time stability of result



- **9 super-samples give consistent results**
- **Detector and beam line asymmetry effects at a few 10^{-4} level, reproduced by MC**

Systematic effects on Δg	δΔg (10^{-4})
Spectrometer alignment	± 0.1
Spectrometer magnetic field	± 0.3
Beam geometry and stray magnetic fields	± 0.2
Kaon production spactra	± 0.3
Resolution and fitting	± 0.2
Accidental activity (pile-up)	± 0.2
Total systematics	± 0.6
L1 trigger efficiency	± 0.3
L2 trigger efficiency	-0.1 ± 0.3

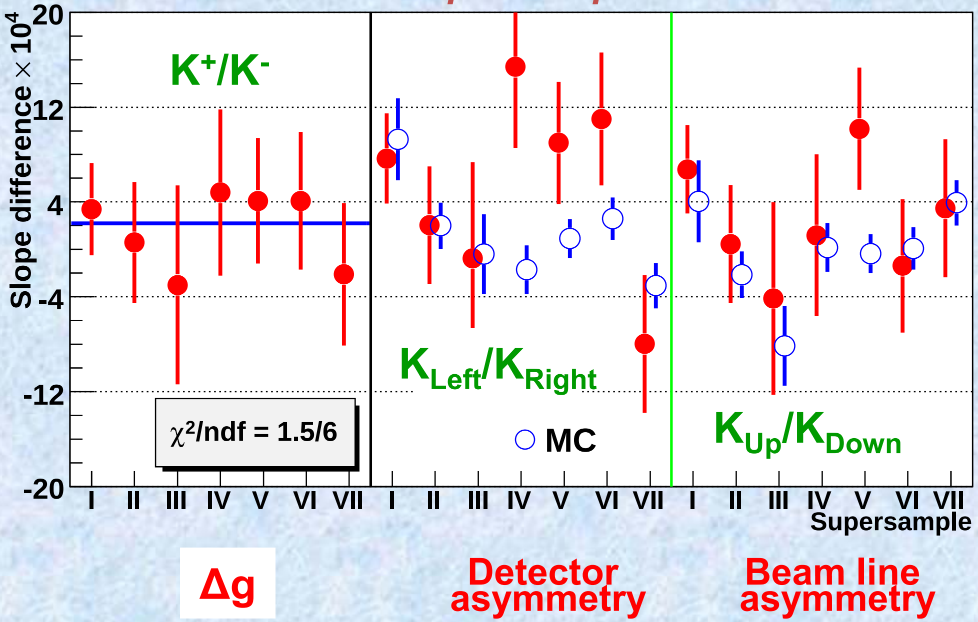
$A_g = (-1.5 \pm 2.2) \times 10^{-4}$

A factor ~ 20 better precision than previous experiments

Result compatible with SM predictions
No evidence for New Physics

$K^{\pm} \rightarrow \pi^{\pm}\pi^{0}\pi^{0}$: A_g^0 final result (2003+2004)

7 super-samples



Statistical precision in A_g^0 similar to $K^{\pm} \rightarrow \pi^{\pm}\pi^{+}\pi^{-}$ mode despite 34 times less events: $|g^0/g^{\pm}| \sim 3$.

Final result consistent with SM predictions:

$$A_g^0 = (1.8 \pm 1.8) \times 10^{-4}$$

Systematic effects on Δg	δΔg (10^{-4})
Overlap of LKr showers	± 0.5
L1 HOD trigger efficiency	± 0.1
L1 LKr trigger efficiency	± 0.1
L2 trigger efficiency	± 0.3
Stray magnetic fields	± 0.1
Kaon production spectra	± 0.3
Accidental activity (pile-up)	± 0.2
Total	± 0.7

$K^{\pm} \rightarrow \pi^{\pm}\pi^{0}\pi^{0}$: Fit of the quadruple ratio

- Quadruple ratios of different supersamples averaged in u-bins after corrections
- Fitted with f(u) using g and h measured by NA48/2

$$f(u)=n(1+\Delta g u/(1+gu+hu^2))^4$$