Summary on CP Violation with Kaons

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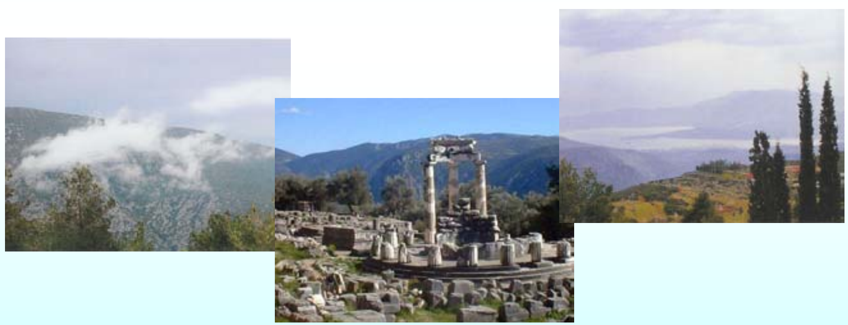
XX Workshop on Weak Interaction and Neutrinos

Delphi, June 7th 2005



On behalf of the NA48 Collaboration

Cambridge, CERN, Chicago, Dubna, Edinburgh, Ferrara, Firenze, Mainz, Northwestern, Perugia, Pisa, Saclay, Siegen, Torino, Vienna

Overview

- Introduction
- CP Violation with Kaons
- Experiments: KLOE, KTeV, NA48
- Results:
  - Direct CP Violation with neutral Kaons
  - Charge Asymmetry in K^0_{e3}
  - $K_S \rightarrow 3\pi^0$
  - Direct CP Violation in $K^{\pm}_{3\pi}$ decays
  - $K_{S,L} \rightarrow \pi^0 l^+ l^-$
- Prospects and conclusions

Introduction

- **Why Kaons**
  - crucial for the present definition of Standard Model
  - search for explicit violation of SM: key element to understand flavour structure of physics beyond SM
- **Motivation for Kaons experiments**
  - Test of fundamental symmetries
    - *CP Violation: charge asymmetry, T violating observables*
    - *CPT test: tigher contraints from Bell-Steinberger rule, K_S/K_L semileptonic decays*
  - Sharpen theoretical tools
    - *Study low energy hadron dynamics: χPT tests and parameter determination, form factors*
  - Probe flavour structure of Standard Model and search for explicit violation (e.g. Lepton Flavour Violation)
    - *Rare decays suppressed (FCNC: 2nd order weak interactions) or not allowed by SM*
    - *Sensitivity to physics BSM*

CP Violation with Kaons

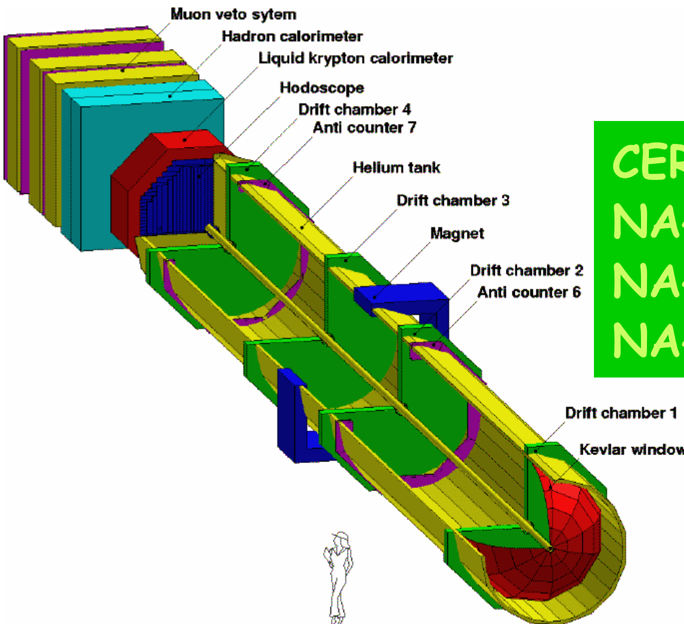
CP Violation: a window to physics beyond SM

Brief History of CP Violation

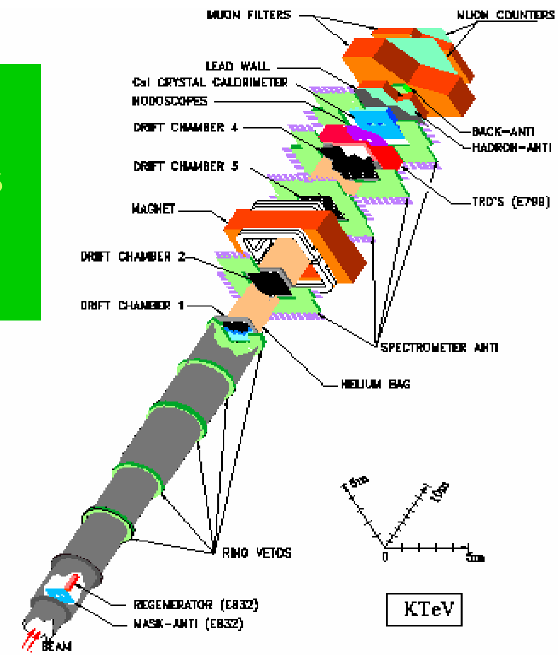
- **1964:** CP violation in K^0 *(Cronin, Christenson, Fitch, Turlay)*
- **1993-99:** Direct CP violation in K^0 *(NA31, NA48, KTeV)*
- **2001:** CP violation in B^0 decay with oscillation *(Babar, Belle)*
- **2004:** Direct CP violation in B^0 *(Belle, Babar)*

- CP Violation in Kaon decays can occur either in $\bar{K}^0$-K^0 mixing or in the decay amplitudes
- Only Direct CP Violation occurs in $K^\pm$ decays (no mixing)
- Complementary observables to measure Direct CP Violation in Kaons: ε'/ε, rare decays, A_g

Experiments with Kaons

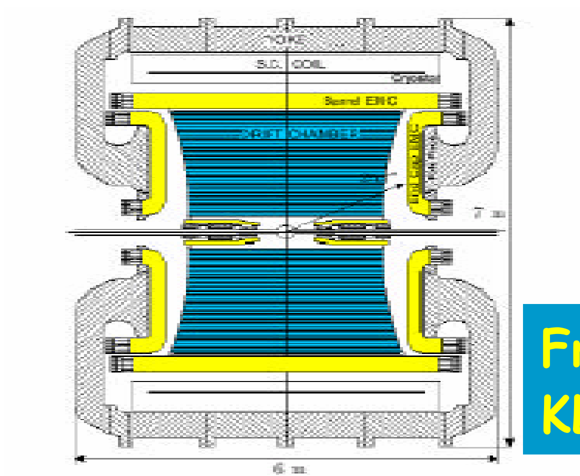


CERN
NA48 1997-2001 K_L, K_S
NA48/1 2000,2002 K_S
NA48/2 2003-2004 $K^{\pm}$



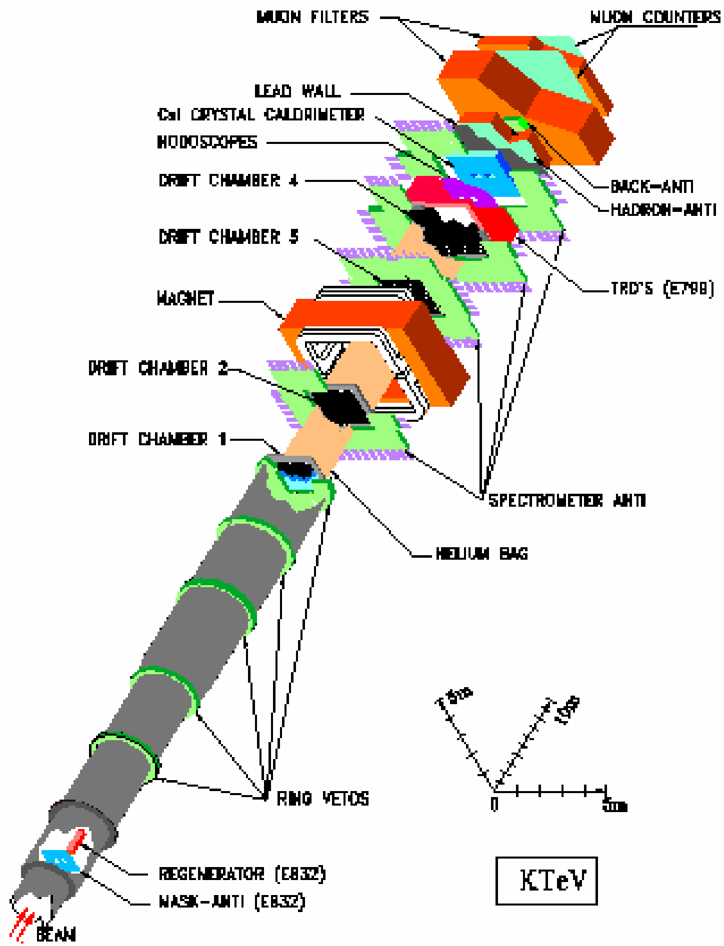
Active Experiments

Fermilab
KTeV: 1997,1999 K_L, K_S



Frascati - DaΦne
KLOE > 2000 $K_S, K_L, K^{\pm}$

FNAL - KTeV Experiment



"Vacuum" beam $\rightarrow K_L$ beam

"Regenerator" beam $\rightarrow K_L + \rho K_S$ beam

- **Parallel K beams:**
  - 2 proton lines (~ 10^{12} ppp)
  - K_S from K_L on Regenerator (scintillator plates),
  - K_S identification via x-y position
  - switches beam line once per cycle
- **$\pi^+\pi^-$: Magnetic Spectrometer**

  $\sigma(p)/p \cong 0.17\% \oplus 0.007\ p[GeV/c]\%$
- **$\pi^0\pi^0$: CsI calorimeter**

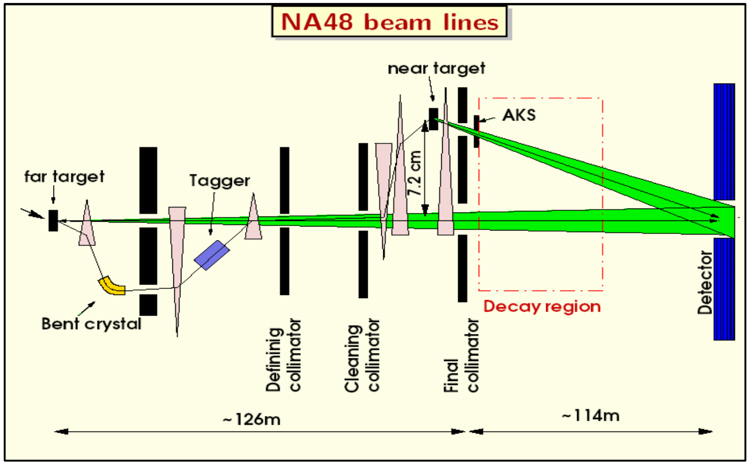
  $\sigma(E)/E \cong 2.0\%/\sqrt{E} \oplus 0.45\%$

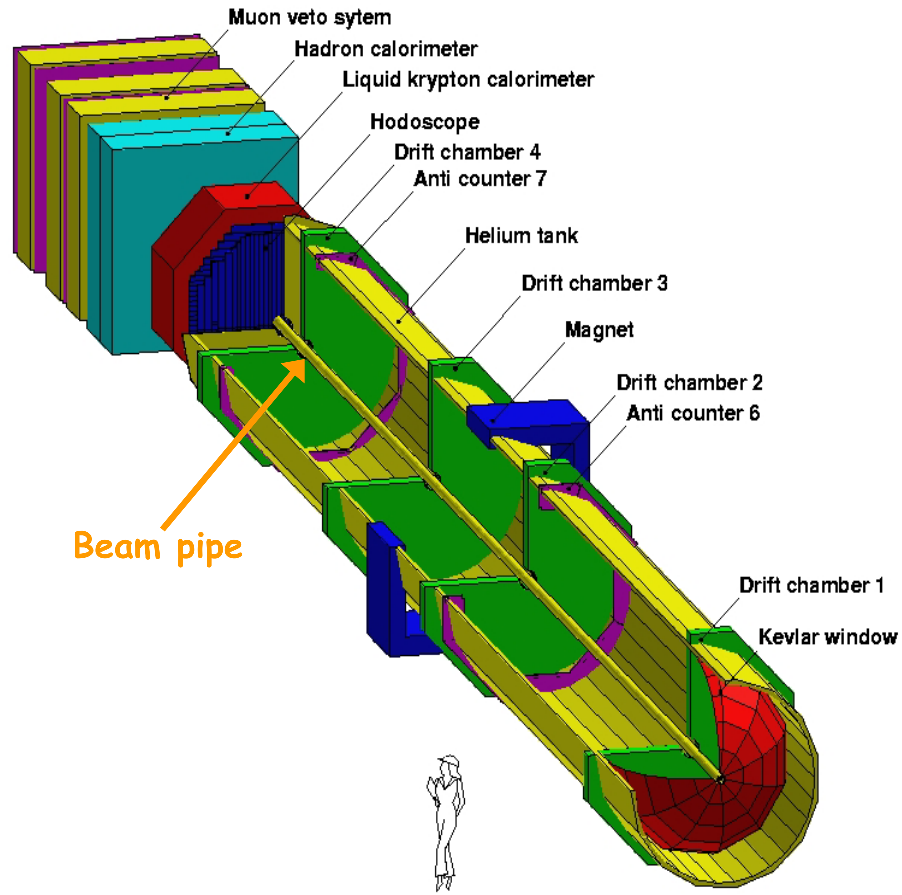
$\sigma_M(\pi^0\pi^0) \sim \sigma_M(\pi+\pi-) \sim 1.5$ MeV

- **Photon veto and muon veto**

Experimental Program
KTeV: 1997,1999 K_L, K_S

CERN - NA48 Experiment





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

  $\Delta p/p = 1.0\% \oplus 0.044\% \times p$ [GeV/c]
- **$\pi^0\pi^0$: LKr Calorimeter**

  $\Delta E/E = 3.2\%/\sqrt{E} \oplus 9\%/E \oplus 0.42\%$ [GeV]

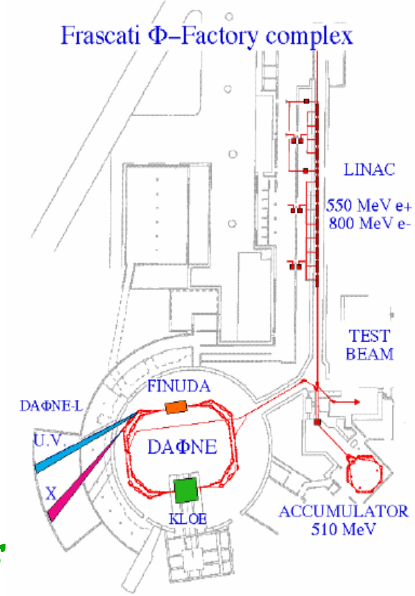
$\sigma_M(\pi^0\pi^0) \sim \sigma_M(\pi^+\pi^-) \sim 2.5$ MeV

- **Photon and muon veto**

Experimental Program

NA48	1997-2001	K_L, K_S
NA48/1	2000,2002	K_S
NA48/2	2003-2004	$K^{\pm}$

LNF DaΦne: the Φ Factory

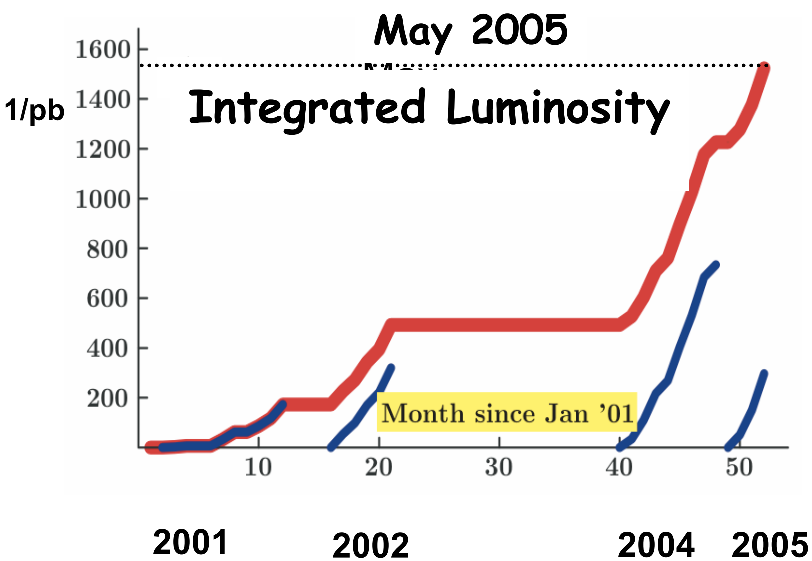


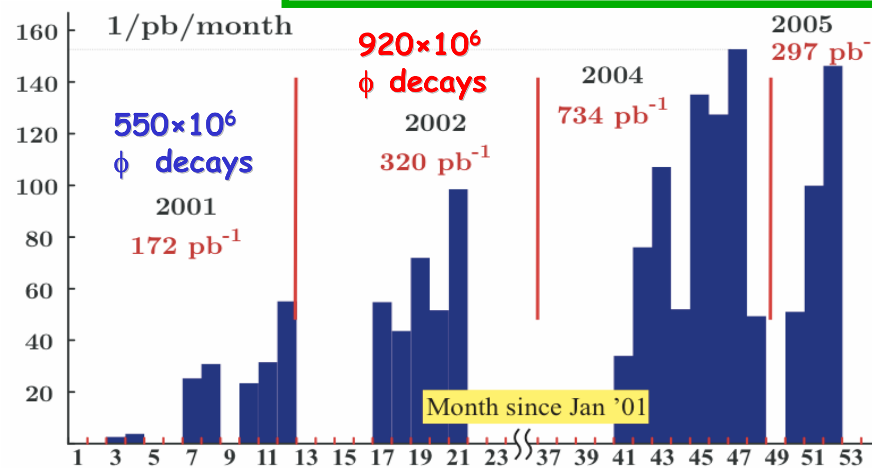
Φ Factory: e^+e^- collider@$\sqrt{s}$ =1019.4 MeV = M_Φ

- Φ Decays: $BR(\Phi \to K_L K_S)$=34.3%; $BR(\Phi \to K^+K^-)$=49.31%
- tagged K decays from $\Phi \to \bar{K}K$ ⇒ pure K beams

  clean investigation of K decays and precision measurements
- KLOE data taking: 2000-01-02-04-05

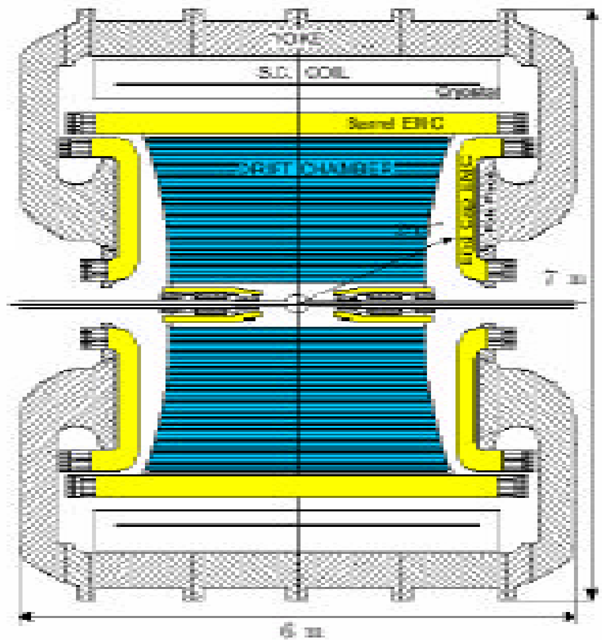
New KLOE run in progress
- L_{peak}= 1.4 × 10^{32} $cm^{-2}s^{-1}$
- Goal: collect 2 fb^{-1} by end 2005





(Recent results from KLOE: S. Dell'Agnello – LNF SC Open Meeting, may '05 and M. Martini – Krare Workshop@LNF, may '05)

LNF: the KLOE detector



EM Calorimeter:
Lead and scintillating fibres

$$\frac{\sigma(E)}{E} = \frac{5.7\%}{\sqrt{E(GeV)}}$$

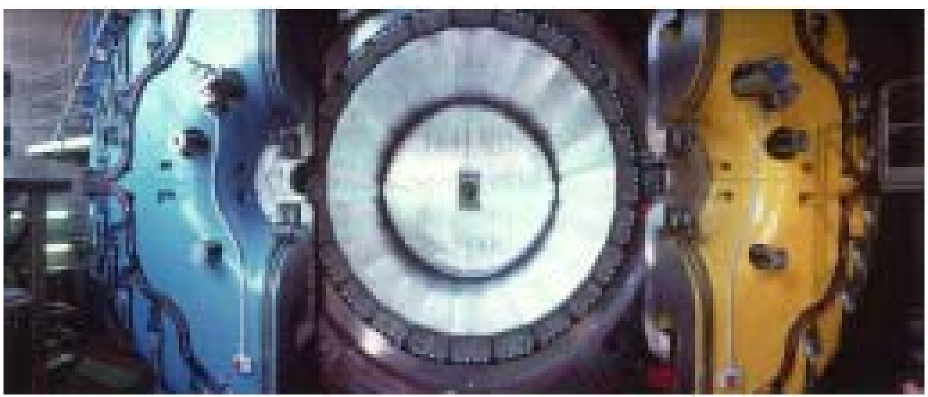
$$\sigma(t) = \frac{54\,ps}{\sqrt{E(GeV)}} \oplus 50\,ps$$

Drift Chamber:
Stereo geometry

$$\delta p / p \approx 4 \times 10^{-3}$$

$$\sigma_{r\phi} = 150\,\mu m$$

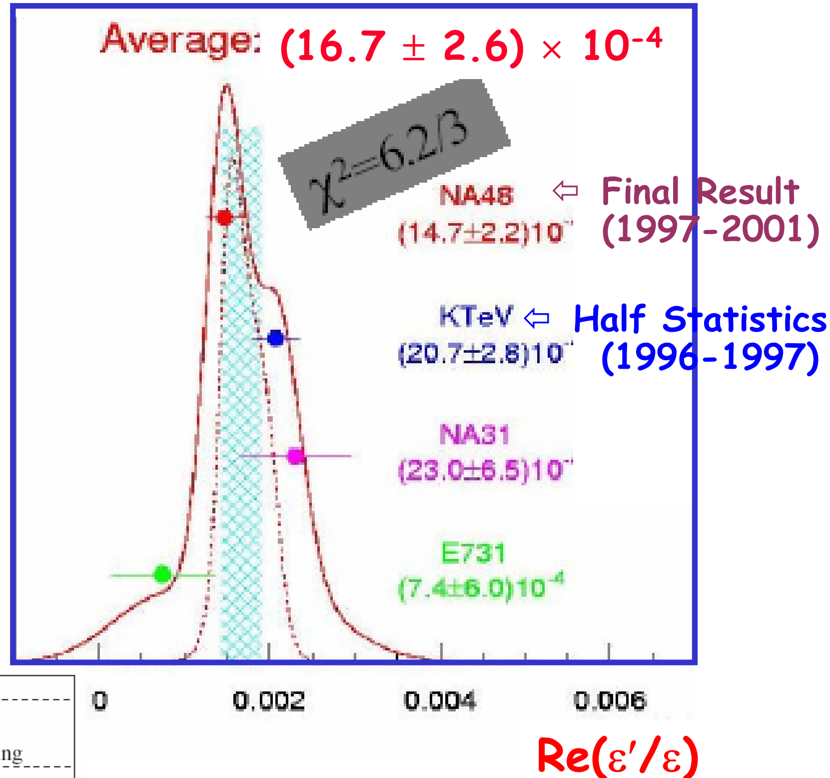
$$\sigma_z = 2\,mm$$

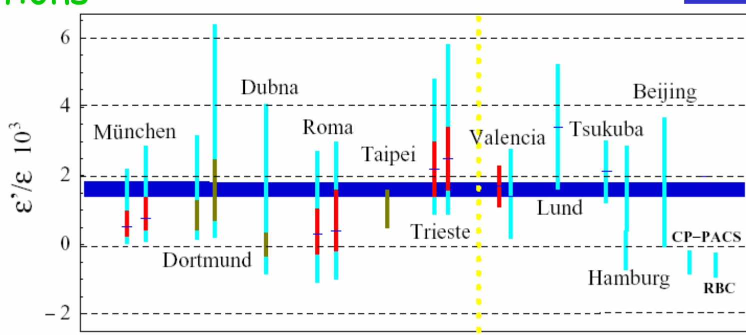


The recent past

Direct CP Violation: experimental results on ε′/ε

- Direct CPV established in $K^0 \to \pi\pi$ by NA48 and KTeV
  - more results expected (KTeV, KLOE)
  - no third generation experiments
- Result (roughly) compatible with SM
  - Exclude alternative to CKM mechanism (superweak models and approximate-CP)
  - Despite huge efforts, ε′/ε not yet computed reliably due to large hadronic uncertainties
  - Improvement of the calculation expected with lattice
- New physics may contribute as a correction to SM predictions





K^0_{e3} Charge Asymmetry

- Charge Asymmetry in K^0_{e3} is due to $\bar{K}^0$-K^0 mixing (Indirect CPV)
- Limits on CPT and $\Delta S=\Delta Q$
- Il CPT is conserved and $\Delta S=\Delta Q$:

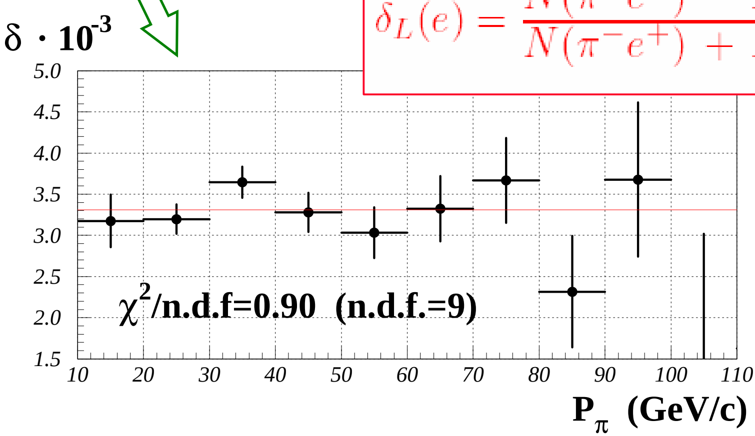
$$\delta_L(e) = \frac{\Gamma(K_L \to e^+\pi^-\nu) - \Gamma(K_L \to e^-\pi^+\bar{\nu})}{\Gamma(K_L \to e^+\pi^-\nu) + \Gamma(K_L \to e^-\pi^+\bar{\nu})} \simeq 2 \times Re(\varepsilon)$$

- Results in NA48 (~2×10^8 K_{e3}) and KTeV (~3×10^8 K_{e3})

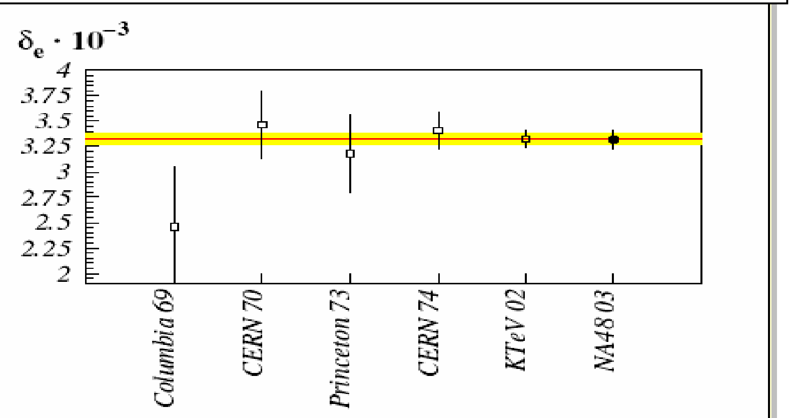
KTeV (2002): $\delta_L(e) = (3.322 \pm 0.058_{stat} \pm 0.047_{syst}) \times 10^{-3}$

NA48 (2003): $\delta_L(e) = (3.309 \pm 0.070_{stat} \pm 0.071_{syst}) \times 10^{-3}$

$$\delta_L(e) = \frac{N(\pi^-e^+) - N(\pi^+e^-)}{N(\pi^-e^+) + N(\pi^+e^-)}$$



PDG2004: $\delta_L(e) = (3.27 \pm 0.12) \times 10^{-3}$



The present

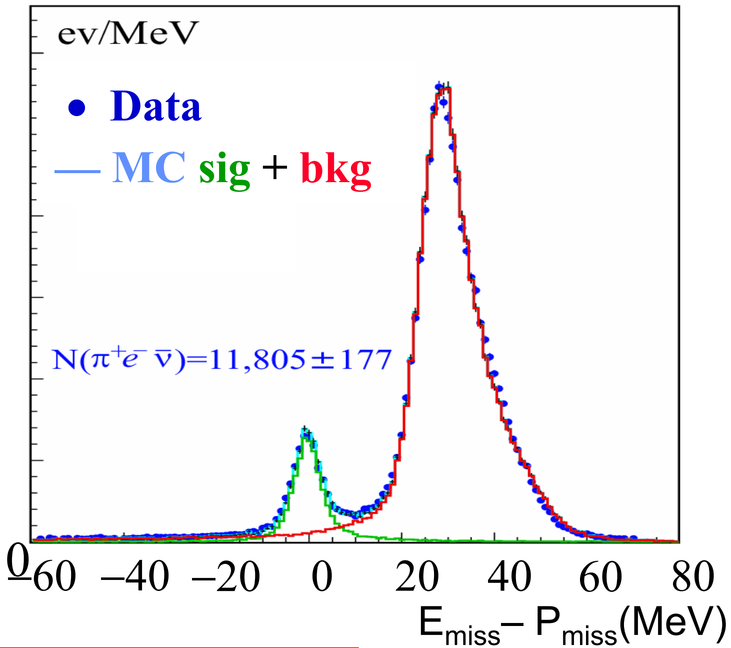
Semileptonic K_S decays

❖ KLOE: first measurement (2002), update in progress

➢ Method:

- K_S tagged by opposite K_L ($\Phi \rightarrow \bar{K}K$)
- Identify πe pairs using TOF
- Event counting by fitting the $[E(\pi e)-P]$ distribution (test for ν)
- Independent measurement of the two charge modes

➢ Selected ~10^4 signal events per charge in the 2001-02 data (0.5 fb^{-1})



❖ New preliminary result:

$$BR(K_S \rightarrow \pi e \nu) = (7.09 \pm 0.07_{stat} \pm 0.08_{syst})\ 10^{-4}$$

❖ CPT Test: new measurement of the charge asymmetry in K_S:

$$\delta_S(e) = (-2 \pm 9 \pm 6) \times 10^{-3}$$

($\delta_L(e) = 3.32 \pm 0.07) \times 10^{-3}$)

CP Violation in $K_S \to \pi^0\pi^0\pi^0$

- $K_S \to 3\pi^0$ is CP violating [$CP(K_S) = +1$, $CP(3\pi^0) = -1$]
- Allowed by SM, but never observed
- According to SM:

$$BR\left(K_S \to 3\pi^0\right) \approx |\varepsilon|^2 \frac{\tau_S}{\tau_L} BR\left(K_L \to 3\pi^0\right) = 1.9 \times 10^{-9}$$

- Last limit from direct search: $BR(K_S \to 3\pi^0) < 1.4\times10^{-5}$ (SND, 1999)
- Can be parametrized with the amplitude ratio η_{000}

$$|\eta_{000}| = \frac{A\left(K_S \to 3\pi^0\right)}{A\left(K_L \to 3\pi^0\right)} = \sqrt{\frac{\tau_L}{\tau_S}\frac{BR\left(K_S \to 3\pi^0\right)}{BR\left(K_L \to 3\pi^0\right)}} \Rightarrow |\eta_{000}| = \varepsilon + i\frac{\mathrm{Im}(A_1)}{\mathrm{Re}(A_1)}$$

If CPT is conserved:
- $\mathrm{Re}(\eta_{000})$: CPV in mixing
- $\mathrm{Im}(\eta_{000})$: direct CPV

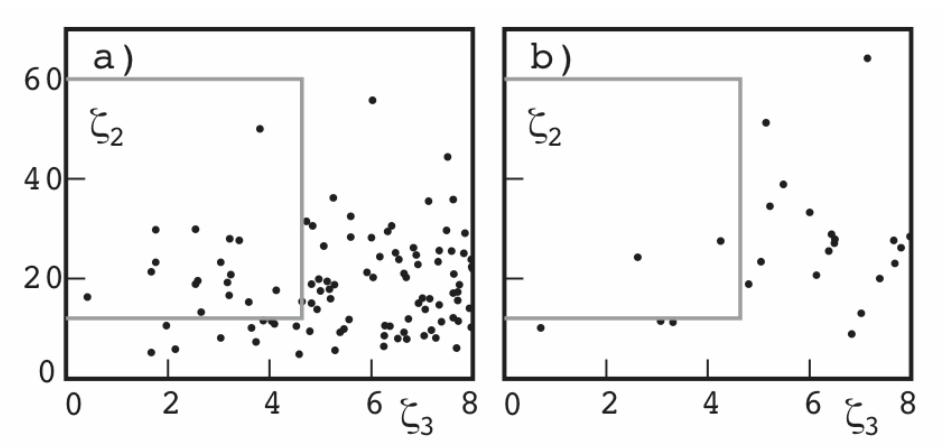
- The uncertainty on $K_S \to 3\pi^0$ amplitude limits the precision on CPT test (Bell-Steinberger relation)

$$\left(1 + i\tan\phi_{SW}\right)\left(\Re e\varepsilon - i\Im m\delta\right) = \sum_f A^*\left(K_S \to f\right)A\left(K_L \to f\right)$$

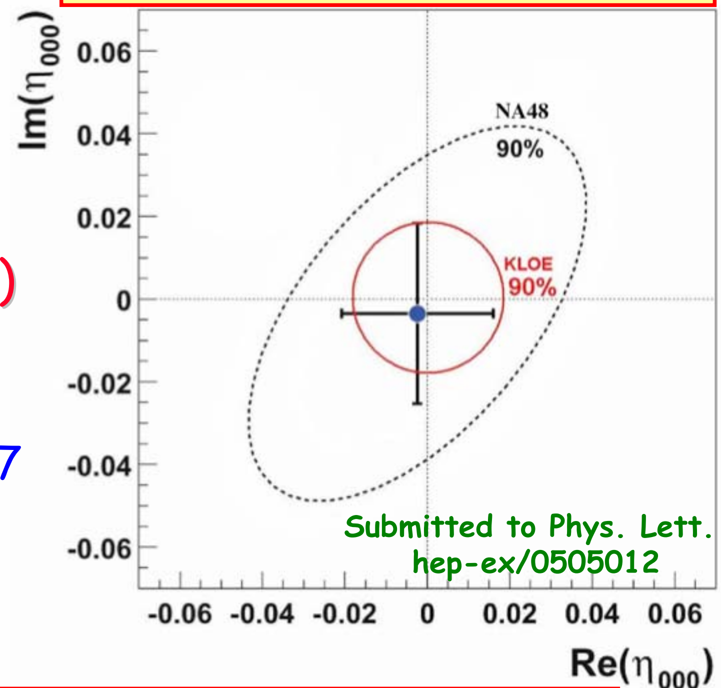
$\not{CP}$ $\not{CPT}$

KLOE search for $K_S \to \pi^0\pi^0\pi^0$

- Direct search, new result
- Rarest decay studied by KLOE so far
- Data sample: 0.5 fb^{-1} (2001-2002 run)
  - 37.8×10^6 (K_L-crash tag + $K_S \to 2\pi^0$)
- Require 6 prompt photons
  - large background ~40K events
- Kinematic fit, $2\pi^0$,$3\pi^0$ estimators (ζ_2, ζ_3)
- After all analysis cuts ($\varepsilon_{3\pi}$ = 24.4%)
  - 2 candidate events found
  - expected background: 3.13 ± 0.82 ± 0.37



$BR(K_S \to 3\pi^0) \leq 1.2 \times 10^{-7}$
@90% CL ⇒ Best limit



Submitted to Phys. Lett.
hep-ex/0505012

Prospects with 2 fb^{-1}:
if background ~ negligible level
UL will improve by factor ~ 10
(down to few 10^{-8})

NA48/1: $K_S \to \pi^0\pi^0\pi^0$ and η_{000}

- Measurement in NA48
  - Sensitivity to η_{000} from K_S-K_L interference superimposed on a huge flat $K_L \to \pi^0\pi^0\pi^0$ component
  - Aim: O(1%) error on Re(η_{000}) and Im(η_{000})
  - Method: measure K_S-K_L interference near the production target
    - *use* ***$3\pi^0$*** *events from near-target run for* ***η_{000}***
    - *normalize to* ***$K_L \to 3\pi^0$*** *from far-target run*
    - *use MC to correct for residuals acceptance difference and Dalitz decays*
- Time evolution of $K_{L,S} \to 3\pi^0$:

$$I_{3\pi^0}(t) \propto \overbrace{e^{-\Gamma_L t}}^{K_L \text{ decay}} + \overbrace{|\eta_{000}|^2 e^{-\Gamma_S t}}^{K_S \text{ decay}} + \underbrace{2\,D(p)\,\left(\mathrm{Re}(\eta_{000}) \cos \Delta m\, t - \mathrm{Im}(\eta_{000}) \sin \Delta m\, t\right)\, e^{-\frac{1}{2}(\Gamma_S + \Gamma_L)\, t}}_{K_L\text{-}K_S \text{ interference}}$$

Dilution $D(p) = \dfrac{N(K^0) - N(\overline{K^0})}{N(K^0) + N(\overline{K^0})} \approx 0.35$ momentum dependent.

NA48/1 results on $K_S \to \pi^0\pi^0\pi^0$

- **Data samples (run 2000):**
  - Near-target run: 4.9×10^6 $K_{L,S} \to 3\pi^0$ data 90×10^6 $K_L \to 3\pi^0$ MC
  - Far-target (K_L) run: 109×10^6 $K_L \to 3\pi^0$ data 90×10^6 $K_L \to 3\pi^0$ MC

- **Fit method:** fit double ratio

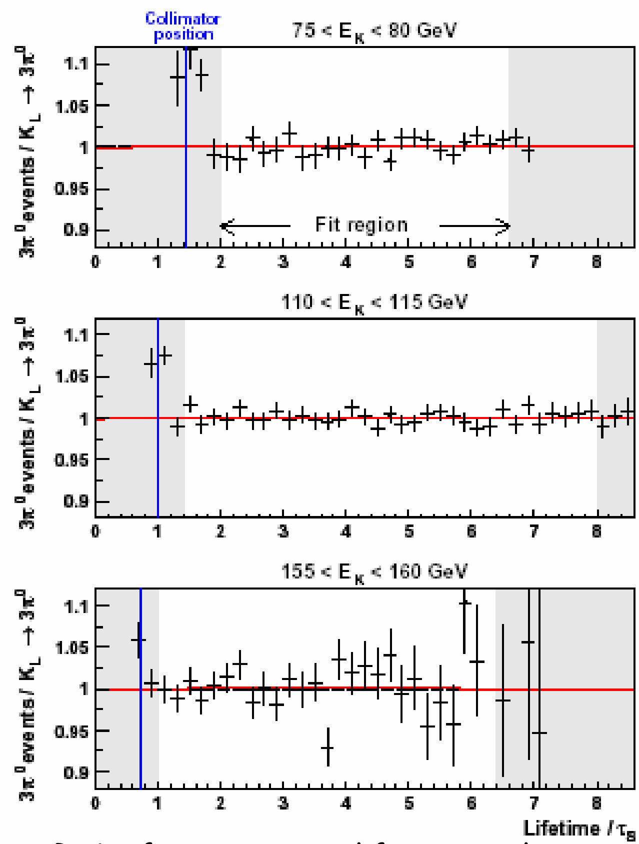
$$\frac{3\pi^0 \text{ (Data, } K_S \text{ run)}}{K_L\to3\pi^0 \text{ (Data, } K_L \text{ run)}} \Bigg/ \frac{K_L\to3\pi^0 \text{ (MC, } K_S \text{ run)}}{K_L\to3\pi^0 \text{ (MC, } K_L \text{ run)}}$$

Final Results (PL B610 2005) :

- $\mathrm{Re}(\eta_{000}) = -0.002 \pm 0.011_{stat.} \pm 0.015_{syst}$
- $\mathrm{Im}(\eta_{000}) = -0.003 \pm 0.013_{stat.} \pm 0.017_{syst}$
- $|\eta| < 0.045$ 90% CL
- $Br(K_S\to3\pi^0) < 7.4 \times 10^{-7}$ 90% CL

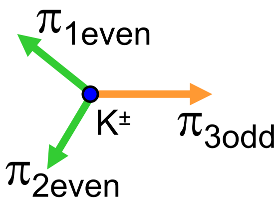
If $\mathrm{Re}(\eta_{000}) = \mathrm{Re}(\varepsilon) = 1.66 \times 10^{-3}$ (CPT):

- $\mathrm{Im}(\eta_{000})_{CPT} = -0.000 \pm 0.009_{stat.} \pm 0.017_{syst}$
- $|\eta|_{CPT} < 0.045$ 90% CL
- $Br(K_S\to3\pi^0)_{CPT} < 2.3 \times 10^{-7}$ 90% CL



Ratio of near-target and far-target data corrected for acceptance (3 Energy intervals)

Direct CP Violation in $K^{\pm}_{3\pi}$



$K^{\pm} \rightarrow 3\pi$ matrix element

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

$BR(K^{\pm}\rightarrow\pi^{\pm}\pi^{+}\pi^{-})$=5.57%

$BR(K^{\pm}\rightarrow\pi^{\pm}\pi^{0}\pi^{0})$=1.73%

Dalitz variables

$$u = \frac{s_3 - s_0}{m_\pi^2}$$

$$v = \frac{s_2 - s_1}{m_\pi^2}$$

$$s_i = (P_K - p_{\pi i})^2 \quad i=1,2,3$$

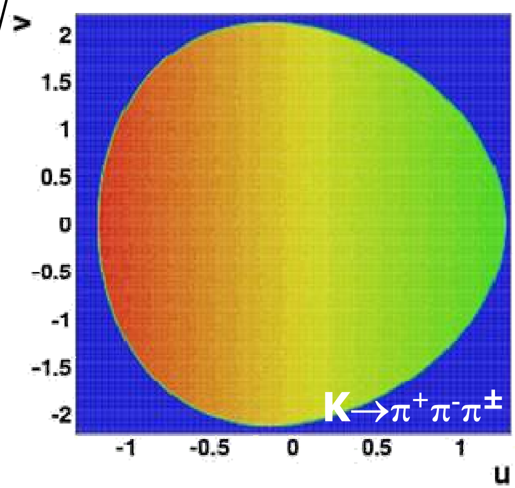
$$s_0 = \tfrac{1}{3}\sum s_i$$

i=3 is the odd pion

$K\rightarrow \pi^{+}\pi^{-}\pi^{\pm}$: g = -0.2154

$K\rightarrow \pi^{0}\pi^{0}\pi^{\pm}$: g = 0.652

|h|, |k| << |g|



K^{+}-K^{-} asymmetry in g

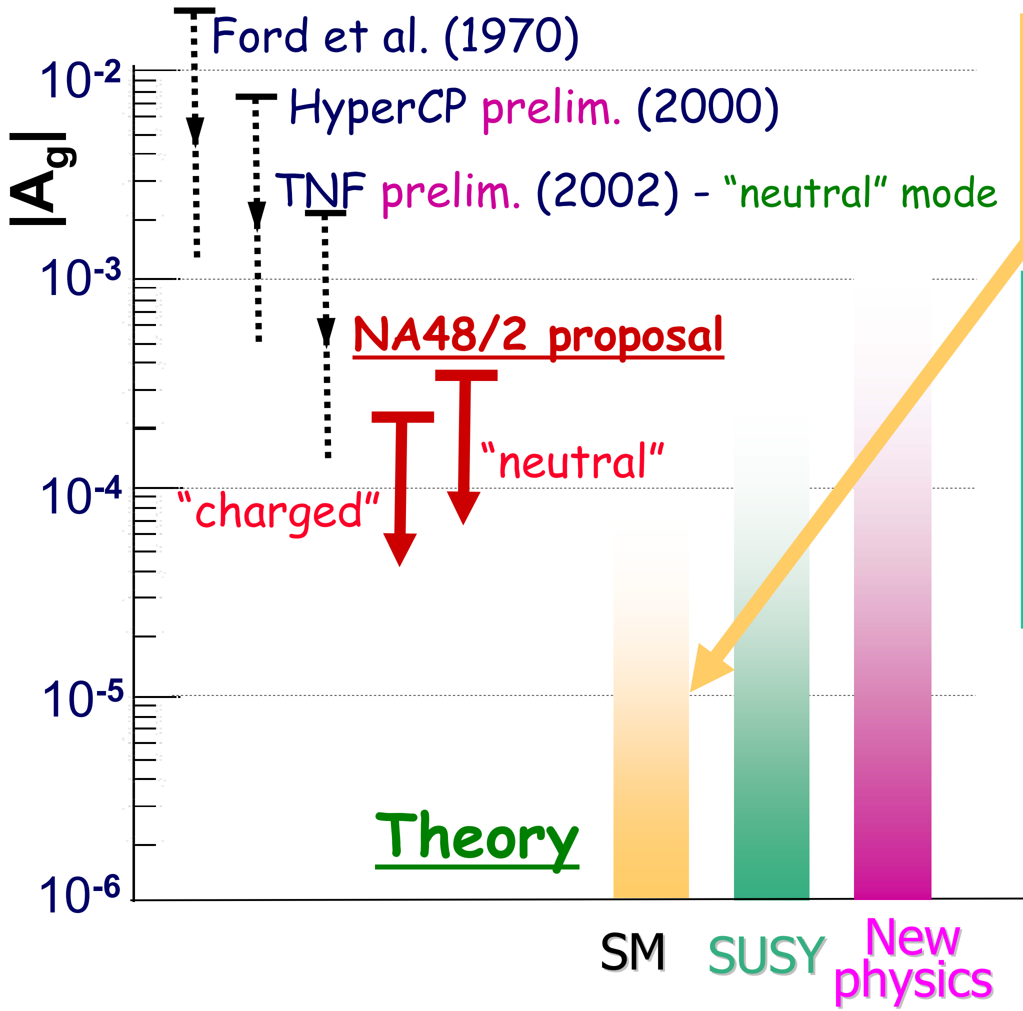
$$A_g = \frac{g_+ - g_-}{g_+ + g_-}$$

⇨ Direct CP violation if $A_g \neq 0$

NA48/2: search for Direct CPV by comparing the linear slopes $g_{\pm}$ for $K^{\pm}$

Experimental and theoretical status

Experimental results



SM estimates of A_g vary within an order of magnitude (few 10^{-6} to 8×10^{-5}).

Models beyond SM predict substantial enhancements partially within the reach of NA48/2.

(theoretical analyses are by far not exhaustive by now)

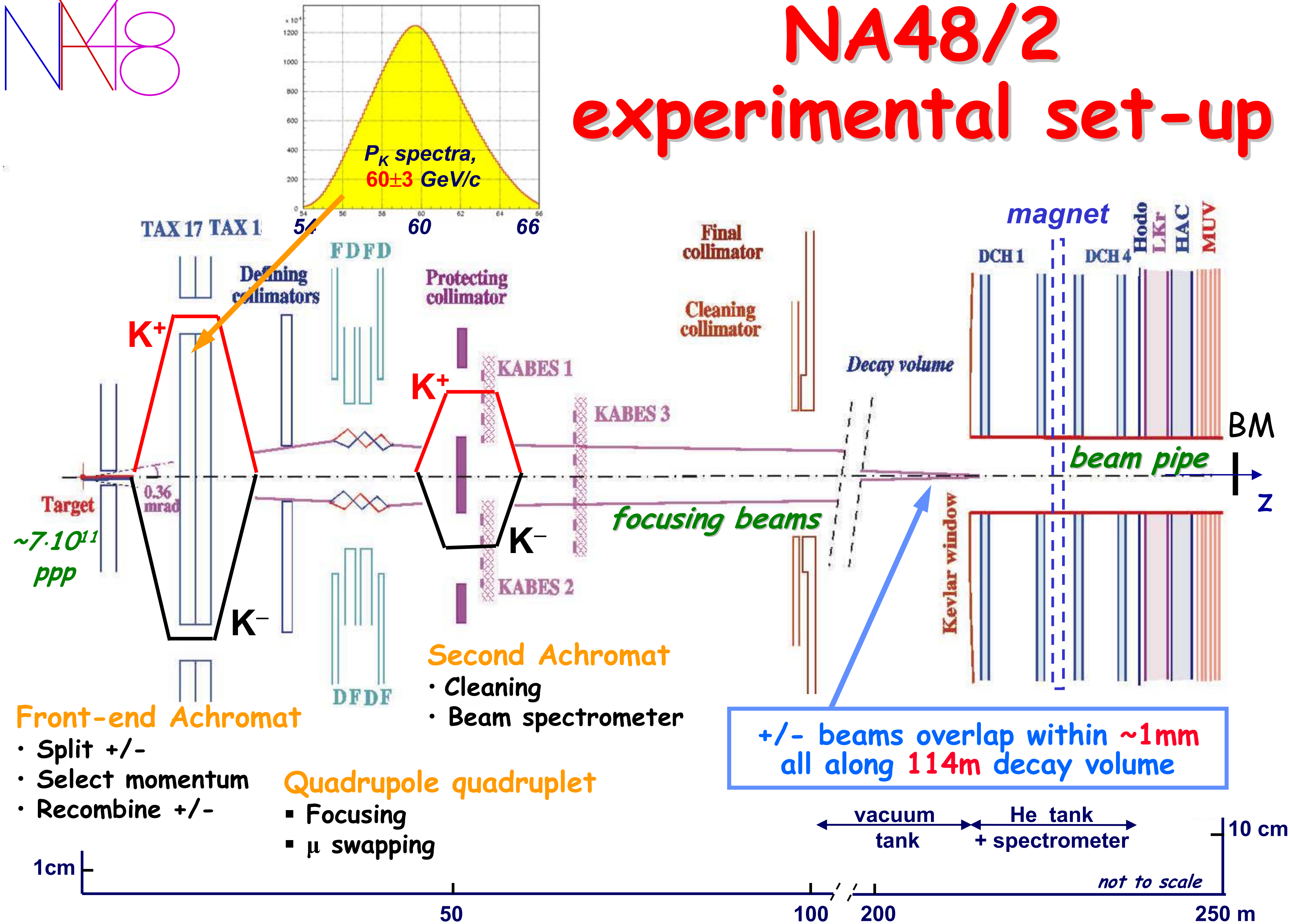
CPV asymmetry in decay width is much smaller than in Dalitz-plot slopes A_g (SM: ~10^{-7}…10^{-6})

NA48/2 goal and method

- **Primary NA48/2 goal:**
  - Measure slope asymmetries in "charged" and "neutral" modes with precisions $\delta A_g < 2.2\times10^{-4}$, and $\delta A_g^0 < 3.5\times10^{-4}$, respectively
  - Statistics required for this measurement: $> 2\times10^9$ in "charged" mode and $> 10^8$ in "neutral" mode

- **NA48/2 method:**
  - Two simultaneous K^+ and K^- beams, superimposed in space, with narrow momentum spectra
  - Detect asymmetry exclusively considering slopes of ratios of normalized u distributions
  - Equalise K^+ and K^- acceptances by frequently alternating polarities of relevant magnets

NA48/2 experimental set-up



NA48/2 Data Taking

Data taking finished
2003 run: ~ 50 days
2004 run: ~ 60 days

Total statistics in 2 years:

$K^{\pm} \rightarrow \pi^{-}\pi^{+}\pi^{\pm}$: ~ 4x10^{9}

$K^{\pm} \rightarrow \pi^{0}\pi^{0}\pi^{\pm}$: ~ 2x10^{8}

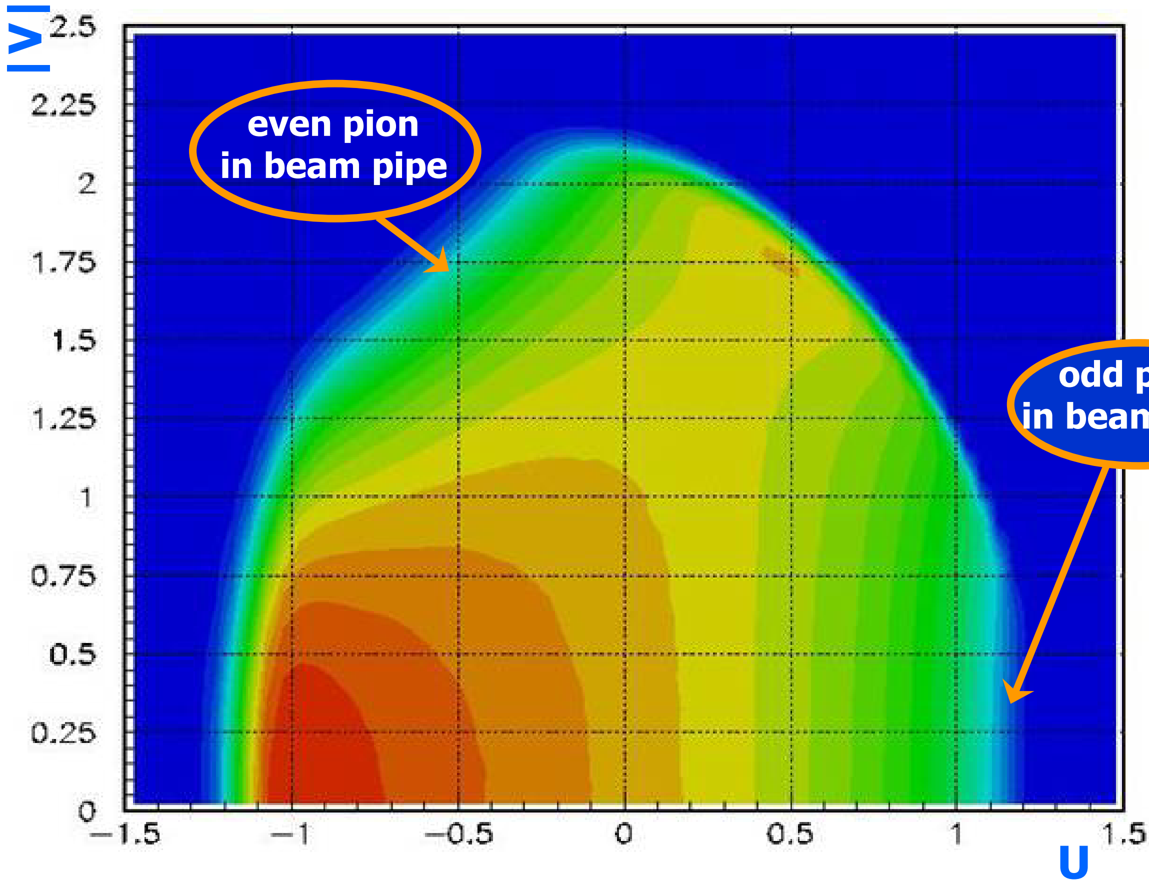
~ 200 TB of data recorded

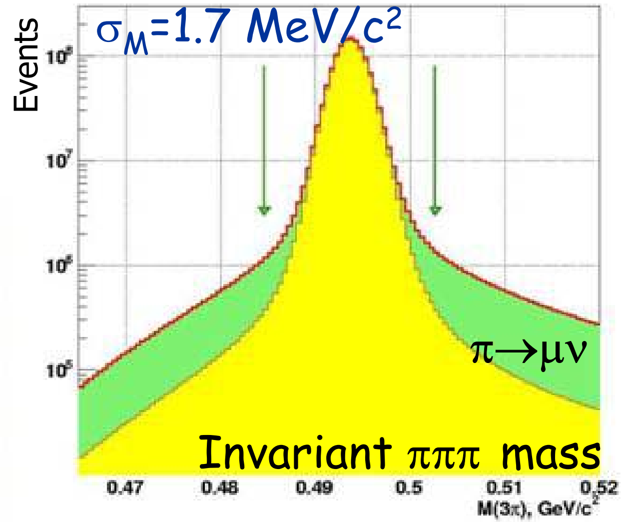
This presentation:
first result based on 2003 $K^{\pm} \rightarrow \pi^{\pm}\pi^{-}\pi^{+}$ sample

$K^{\pm}_{3\pi}$ statistics

Data taking 2003

1.61x10^9 $K^{\pm} \to \pi^{\pm}\pi^{-}\pi^{+}$ events





Accepted statistics

K^+ : 1.03 x10^9 events

K^- : 0.58 x10^9 events

$K^+/K^- \approx 1.8$

A_g measurement strategy - 1

- Use only the slopes of ratios of normalized u-distribution
  - Build u-distributions of K^+ and K^- events: $N^+(u)$, $N^-(u)$
  - Make a ratio of these distributions: $R(u)$
  - Fit a linear function to this ratio: normalised slope ≈ Δg

$$R(u) = \frac{N^+(u)}{N^-(u)} = \bar{R}\,\frac{1+g^+u}{1+g^-u} \approx \bar{R}(1+\Delta g\, u)$$

$$A_g = \frac{\Delta g}{2g} \Rightarrow$$

e.g. uncertainty $\delta A_g < 2.2 \cdot 10^{-4}$ corresponds to $\delta\Delta g < 0.9 \cdot 10^{-4}$

- Compensate unavoidable detector asymmetry inverting periodically the polarity of the relevant magnets:
  - Every day: magnetic field B in the spectrometer (up/down: B+/B-)
  - Every week: magnetic field A of the achromat (up/down: A+/A-)

A_g measurement strategy - 2

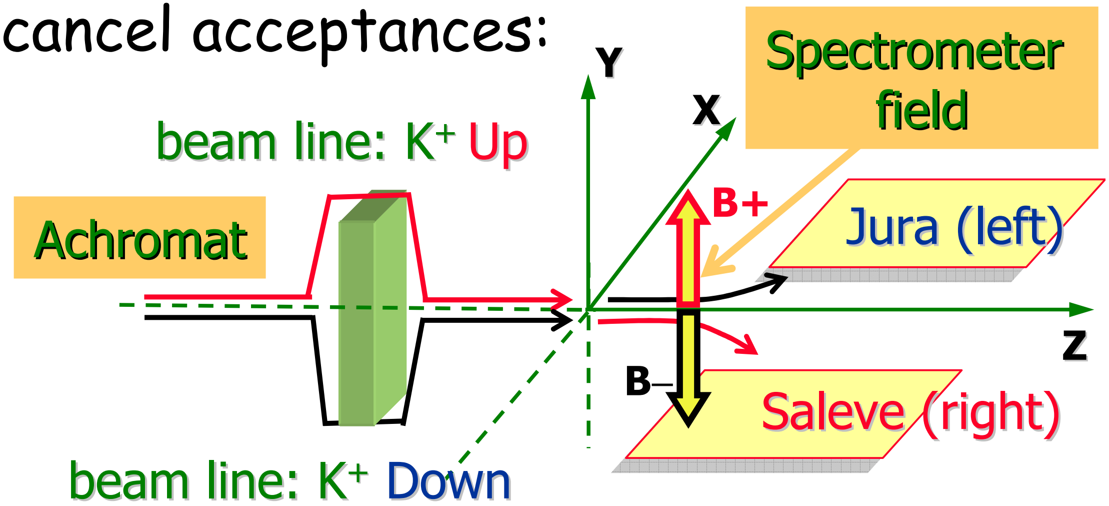
Four ratios are used to cancel acceptances:

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

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

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

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



- beam line polarity (U/D)
- direction of kaon deviation in the spectrometer (S/J)

❖ "Supersample" data taking strategy:
- achromat polarity (A) was reversed on weekly basis
- spectrometer magnet polarity (B) was reversed on daily basis

⇨ 1 Supersample ~ 2 weeks ⇨ 2003 data: 4 Supersamples

NA48 A_g measurement strategy - 3

Quadruple ratio is used for further cancellation:

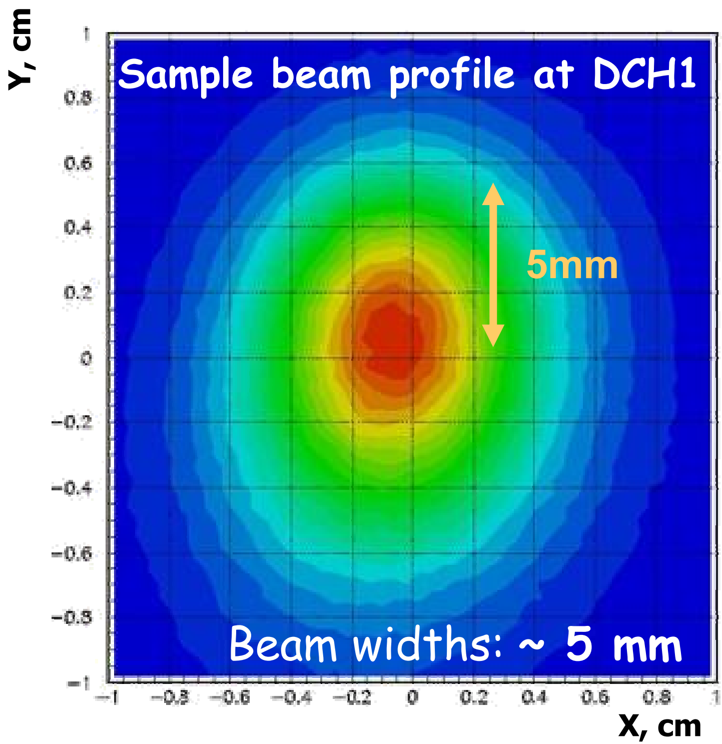
$$\mathbf{R} = R_{US} \times R_{UJ} \times R_{DS} \times R_{DJ} \sim 1 + 4 \times \Delta g \times u$$

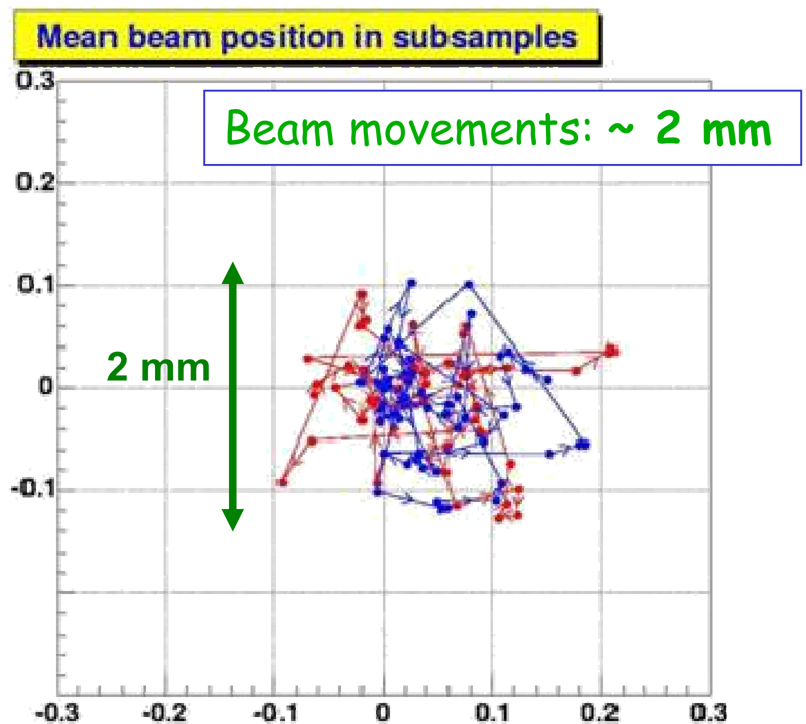
- Cancellation of systematic biases:
  1) Beam rate effects: global time-variable biases (K^+ and K^- simultaneously recorded)
  2) Beam geometry difference effects: beam line biases (K^+ beam up / K^- beam up etc)
  3) Detector asymmetries effects (K^+ and K^- illuminating the same detector region)
- Acceptance is defined respecting azimuthal symmetry:
  4) Effects of permanent stray fields (earth, vacuum tank magnetisation) cancels

The result is sensitive **only** to <u>**time variation**</u> of **asymmetries** in experimental conditions (beam+detector) with a characteristic time smaller than the corresponding field-alternation period (e.g. the supersample time scale: beam-week, detector-day)

Beam systematics

❖ **Time variations of beam geometry**
- Acceptance largely defined by central beam hole edge (R~10 cm)
- Acceptance cut defined by a (larger) "virtual pipe" - centered on averaged beam positions - as a function of charge, time and K momentum

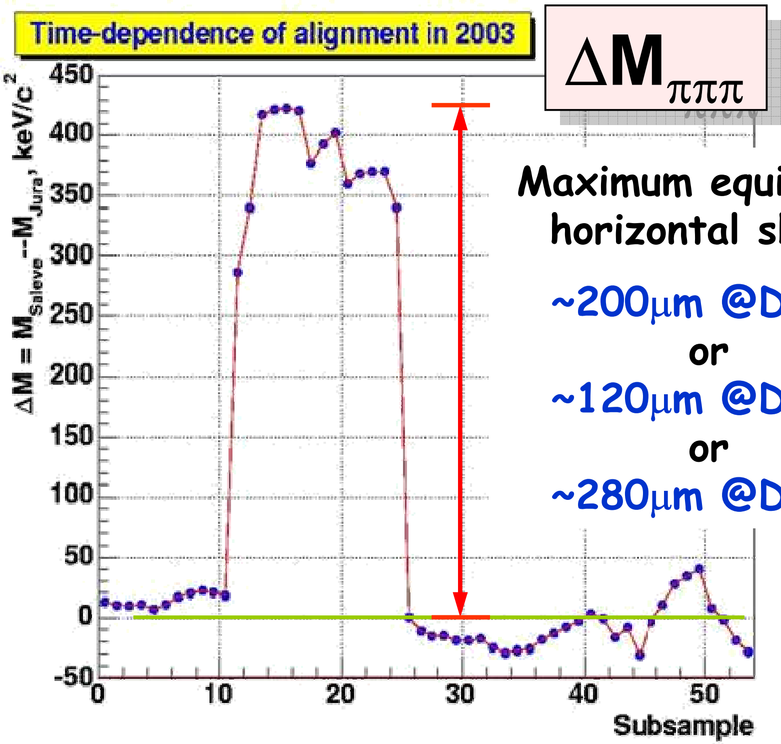




Spectrometer systematics

❖ Time variations of spectrometer geometry

- DCH drifts by O(100μm) in a 3 month run: asymmetry in p measurement
- alignment is fine tuned by forcing the average value of the reconstructed invariant 3π masses to be equal for K^+ and K^-



Maximum equivalent horizontal shift:

~200μm @DCH1
or
~120μm @DCH2
or
~280μm @DCH4

❖ Momentum scale

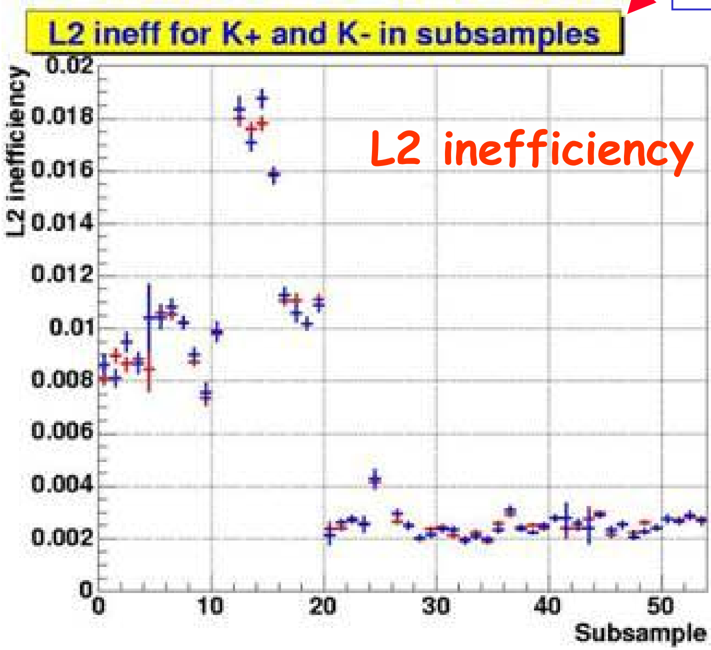
- due to variations of the magnet current (10^{-3})
- sensitivity to a 10^{-3} error on field integral: $\Delta M \approx 100$ keV
- mostly cancels due to simultaneous beams
- in addition, it is adjusted by forcing the average value of reconstructed invariant 3π masses to the PDG value of M_{K+}

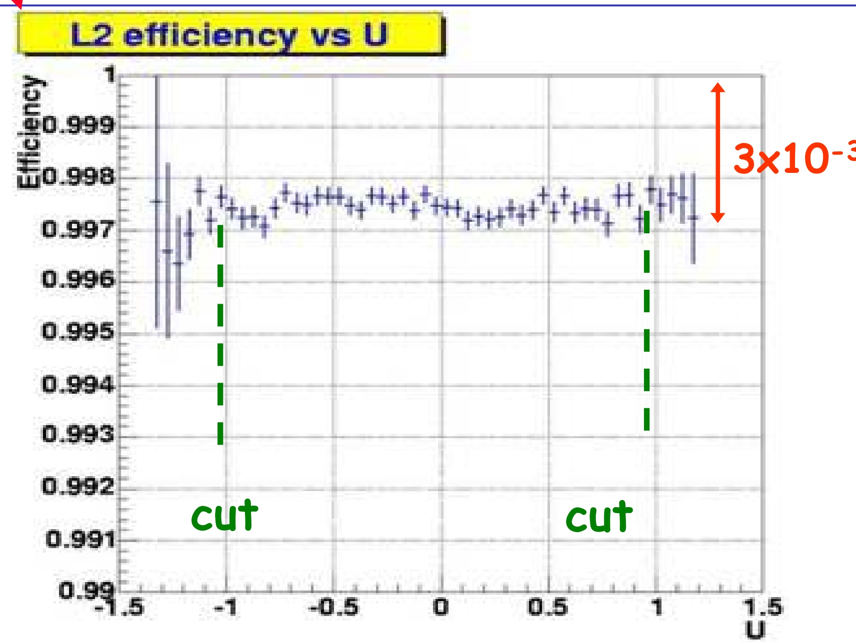
Trigger systematics

- Measure inefficiencies using control data from low bias triggers
- Assume rate-dependent trigger inefficiencies symmetric

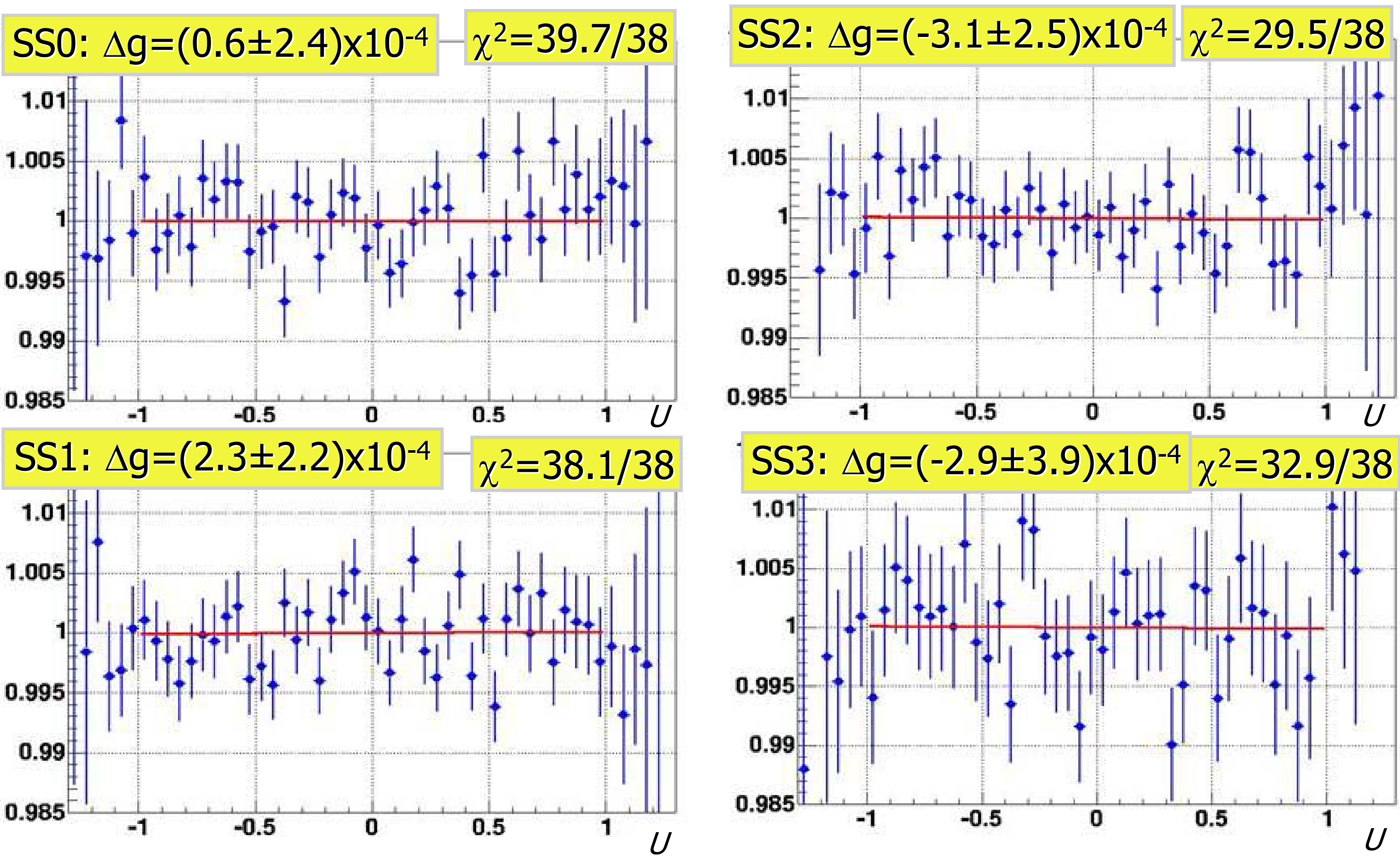
L1 trigger (2 hodoscope hits)
stable and small inefficiency
(≈ $0.7 \cdot 10^{-3}$): no correction

L2 trigger (online vertex reconstruction):
time-varying inefficienciy (≈ 0.2% to 1.8%)
flat in u within measurement precision:
u-dependent correction applied





Fit linearity: 4 Supersamples



Systematics summary and results

Combined result
in $\Delta g \times 10^4$ units
(3 independent analyses)

	Raw	Corrected for L2 eff
SS0	0.0±1.5	0.5±2.4
SS1	0.9±2.0	2.2±2.2
SS2	-2.8±2.2	-3.0±2.5
SS3	2.0±3.4	-2.6±3.9
Total	**-0.2±1.0**	**-0.2±1.3**
χ^2	2.2/3	3.2/3

L2 trigger correction included

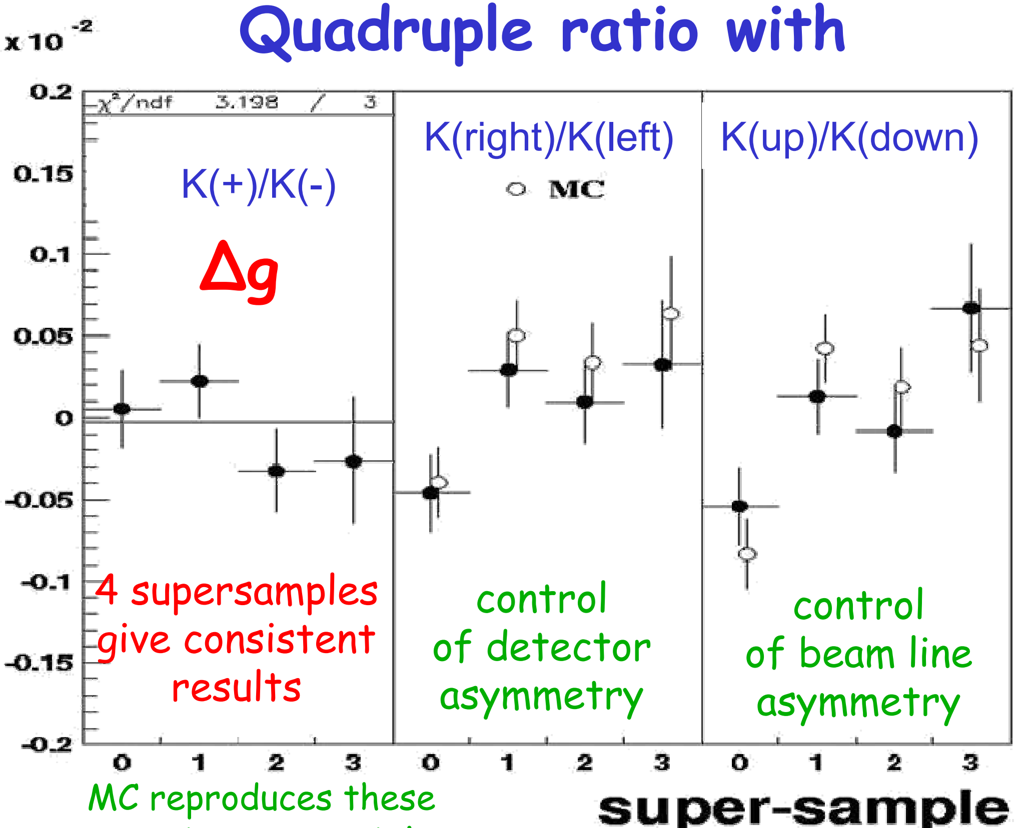
Conservative estimation of systematic uncertainties	Effect on $\Delta g \times 10^4$
Acceptance and beam geometry	0.5
Spectrometer alignment	0.1
Analyzing magnet field	0.1
$\pi^\pm \to \mu\nu$ decay	0.4
U calculation and fitting	0.5
Pile-up	0.3
Systematic errors of statistical nature	
Trigger efficiency: L2	0.8
Trigger efficiency: L1	0.4
Total systematic error	**1.3**

Stability of the result

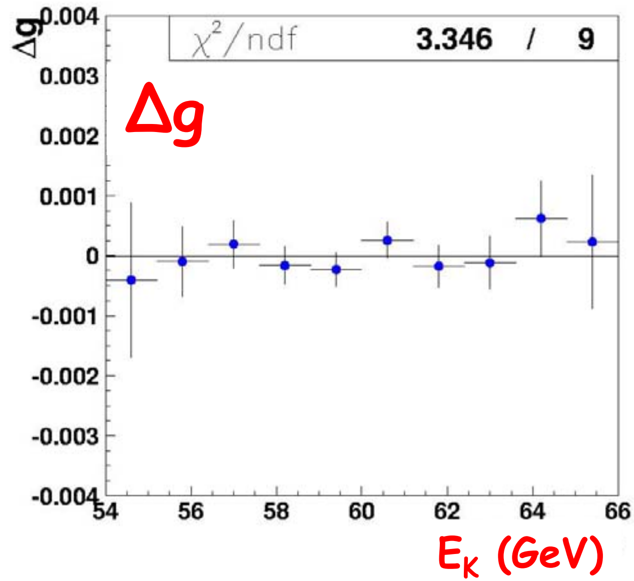
$$\Delta g = (-0.2 \pm 1.0_{stat.} \pm 0.9_{stat.(trig.)} \pm 0.9_{syst.}) \times 10^{-4}$$

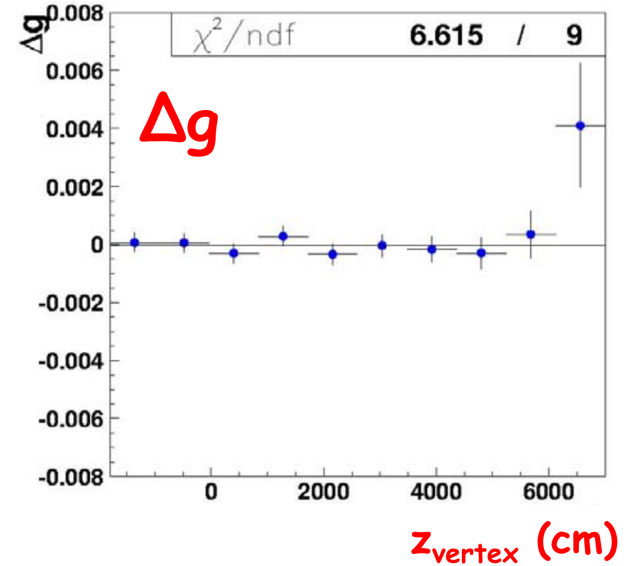
$$\Delta g = (-0.2 \pm 1.7) \times 10^{-4}$$

Quadruple ratio with



MC reproduces these apparatus asymmetries

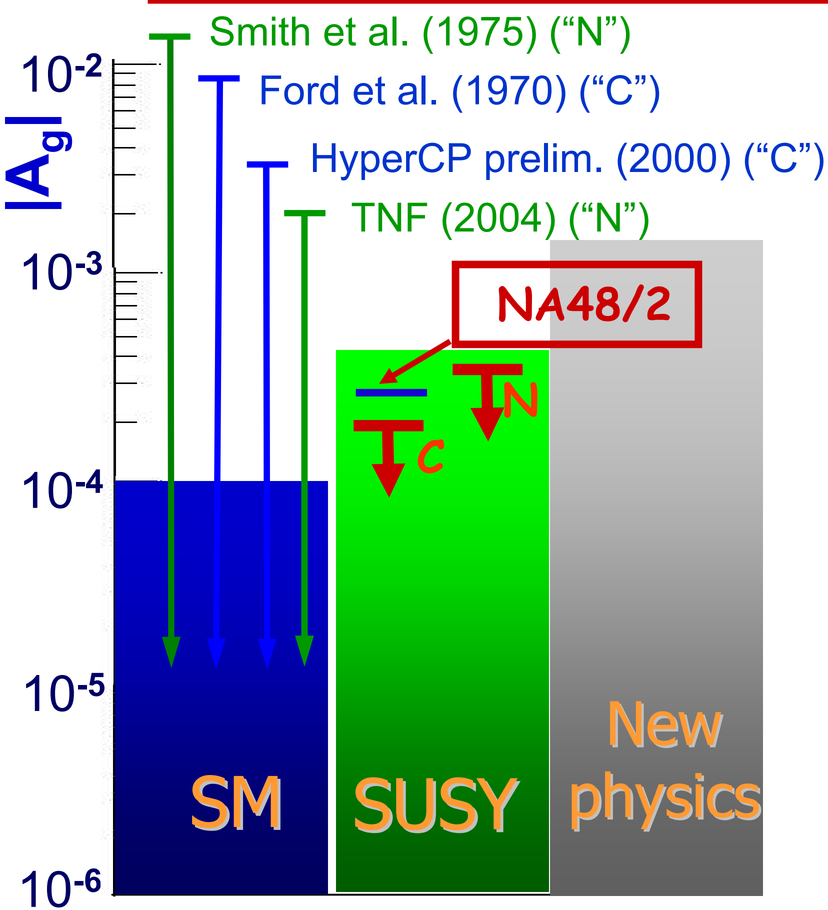




Preliminary result on A_g

$$A_g = (0.5 \pm 2.4_{stat.} \pm 2.1_{stat.(trig.)} \pm 2.1_{syst.}) \times 10^{-4}$$

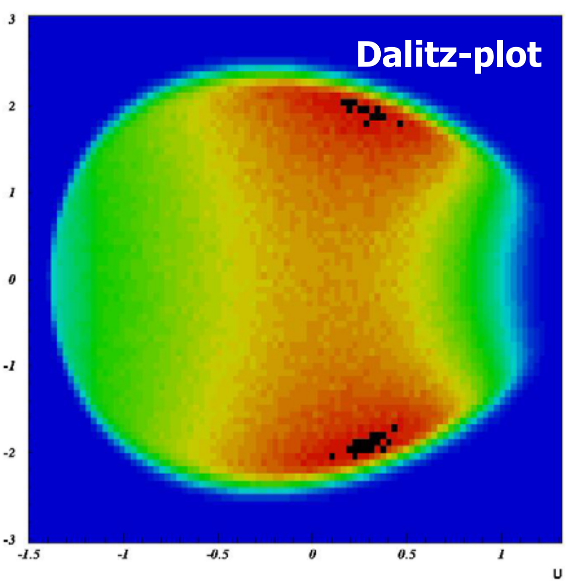
$$A_g = (0.5 \pm 3.8) \times 10^{-4}$$ NA48/2 - 2003 data

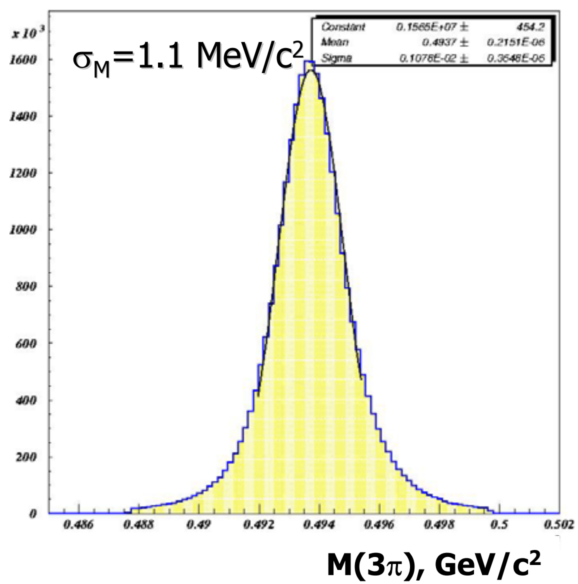


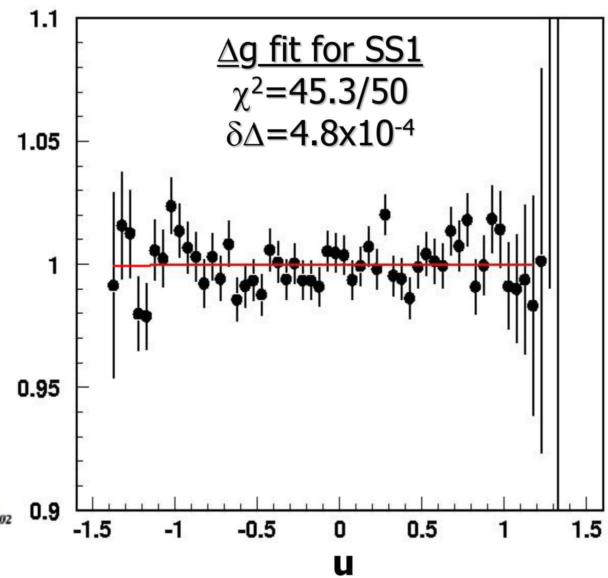
- This is a preliminary result, with conservative estimate of the systematic errors
- The extrapolated statistical error 2003+04 is $\delta A_g = 1.6 \times 10^{-4}$
- 2004 data: expected smaller systematic effects (more frequent polarity inversion, better beam steering)

Neutral mode asymmetry
$K^{\pm} \rightarrow \pi^{\pm}\pi^{0}\pi^{0}$

- Statistics analyzed: 28 × 10^6 events (1 month of 2003)
- Statistical error with analyzed data: $\delta A_g = 2.2 \times 10^{-4}$
- Extrapolation to 2003 + 2004 data: $\delta A_g = 1.3 \times 10^{-4}$
- Similar statistical precision as in "charged" mode
- Possibly larger systematics errors







A glance to the future

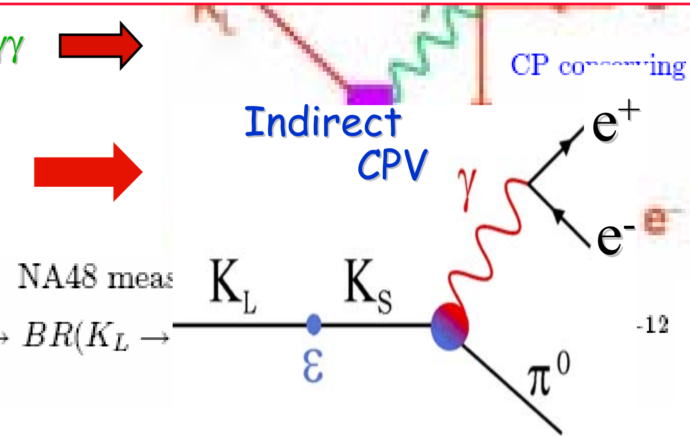
Search for $K_S \to \pi^0 e^+ e^-$

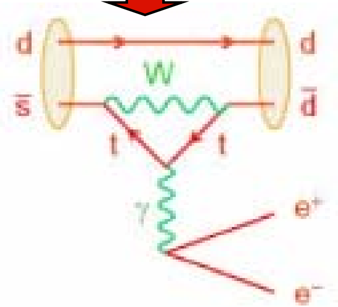
Motivation: determination of the indirect CP violating amplitude of the decay $K_L \to \pi^0 e^+ e^-$

$K_L \to \pi^0 e^+ e^-$

- BR(SM)=3-10x10^{-12}, BR($\gamma\gamma e^+e^-$)≈6×10^{-7}
- 3 contribution to this decay (χPT):
  - A_1(CPC): not predicted, derived from $K_L \to \pi^0 \gamma\gamma$ ($K_2 \to \pi^0\gamma^*\gamma^* \to \pi^0 e^+e^-$, NA48, KTeV)
  - A_2(CPV_{Ind}): not predicted, measured by $K_S \to \pi^0 e^+ e^-$ (NA48/1)
  - A_3(CPV_{Dir}): predicted in terms of CKM phase (electroweak penguins and W boxes with top

$$|A_2 + A_3|^2 \to BR\cdot 10^{12} = 15.3(a_s)^2$$
$$-6.8\,(a_s)\{10^4\,\mathrm{Im}(\lambda_t)\} + 2.8\{10^4\,\mathrm{Im}(\lambda_t)\}^2$$





direct CP violating

Proportional to η or $\mathcal{Im}(\lambda_t)$

$$\mathcal{Im}(\lambda_t) = \eta A^2 \lambda^5 \qquad \lambda_t = V_{ts}^* V_{td}$$

$$\to BR(K_L \to \pi^0 e^+ e^-)_{dir} \sim few \times 10^{-12}$$

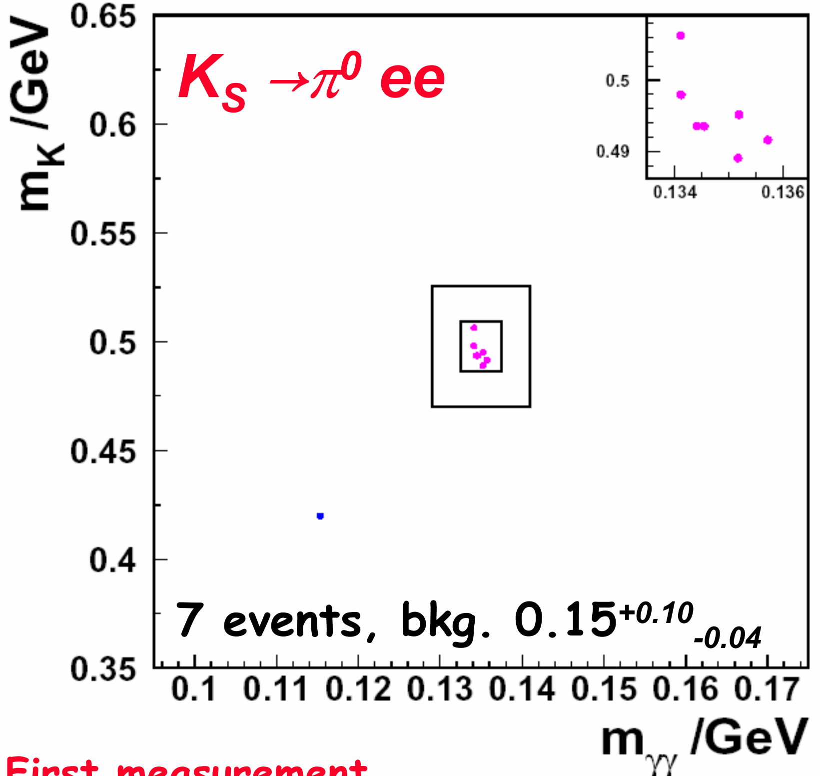
KTeV limits (90%CL)

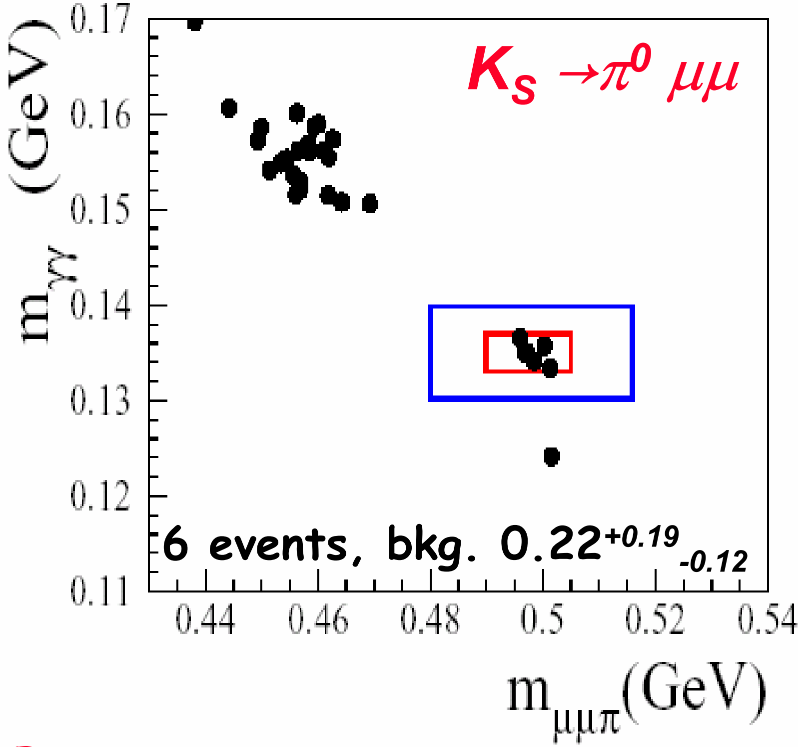
BR(π^0ee) < 2.8×10^{-10}

BR($\pi^0\mu\mu$) < 3.8×10^{-10}

NA48/1: $K^0_S \rightarrow \pi^0 l^+ l^-$

Main motivation for the NA48/1 proposal





First measurement

BR(π^0ee) = $5.8\ ^{+2.8}_{-2.3}$(stat) ± 0.8(syst) × 10^{-9}

$|a_s|=1.06^{+0.26}_{-0.21}$ (stat) ± 0.07 (syst)

PLB 576 (2003)

First measurement

BR($\pi^0\mu\mu$) = $2.9\ ^{+1.4}_{-1.2}$(stat) ± 0.2(syst) × 10^{-9}

$|a_s|=1.55^{+0.38}_{-0.32}$ (stat) ± 0.05 (syst)

PLB 599 (2004)

SM prediction for $K^0_L \to \pi^0 l^+ l^-$

- From K_L measurement: small CPC contribution
- From K_S measurement: indirect CPV contribution dominates
- Sensitivity of BR to CKM phase depends on the (unmeasurable) relative sign of the two CPV terms

Constructive	Destructive
$B_{K^0_L \to \pi^0 e^+ e^-} = 3.7^{+1.1}_{-0.9} \times 10^{-11}$	$B_{K^0_L \to \pi^0 e^+ e^-} = 1.7^{+0.7}_{-0.6} \times 10^{-11}$
$B_{K^0_L \to \pi^0 \mu^+ \mu^-} = 1.5^{+0.3}_{-0.3} \times 10^{-11}$	$B_{K^0_L \to \pi^0 \mu^+ \mu^-} = 1.0^{+0.2}_{-0.2} \times 10^{-11}$

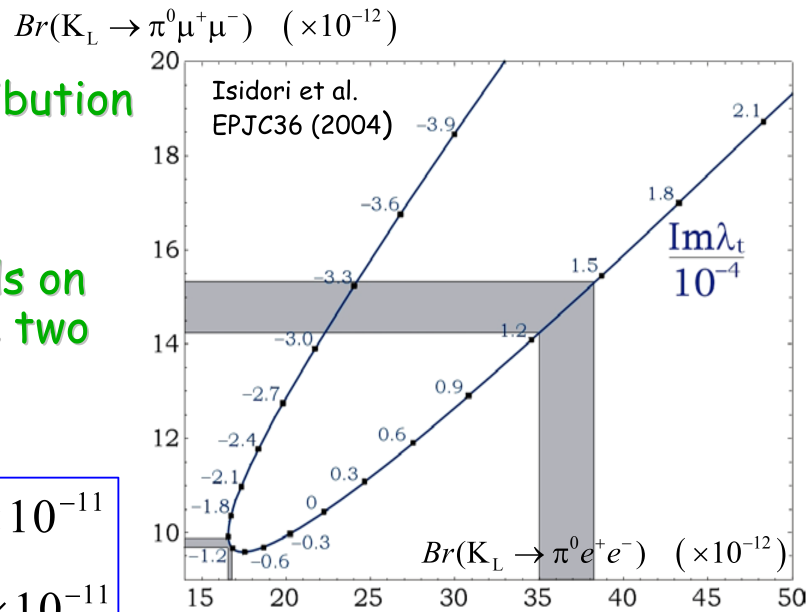
- *Theory: constructive interference favored* *

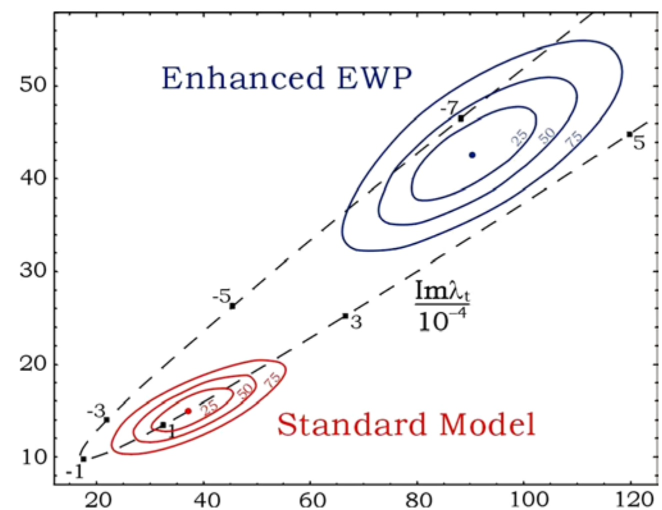
- Sensitivity to new physics: enhanced electroweak penguins would enhance the BR

J. Buras et al.
hep-ph/0402112
NP B697 (2004)

$$B^{NP}_{K^0_L \to \pi^0 e^+ e^-} = 9.0^{+1.6}_{-1.6} \times 10^{-11}$$

$$B^{NP}_{K^0_L \to \pi^0 \mu^+ \mu^-} = 4.3^{+0.7}_{-0.7} \times 10^{-11}$$





* Two indeopendent analysis:
G. Buchalla, G. D'Ambrosio, G. Isidori, Nucl.Phys.B672,387 (2003) - S. Friot, D. Greynat, E. de Rafael, hep-ph/0404136, PL B 595

Prospects and conclusions

- Kaon was central in the definition of SM
- Quantitative tests of CKM mechanism and search for new physics beyond SM are possible with rare Kaon decay mesurements
- High level of precision is attainable
- Constraints to CKM variables and further test of CPV from FCNC processes ("golden decays"):
  - **$K_L \to \pi^0 e^+ e^-$ decays**
  - **$K \to \pi \bar{\nu}\nu$ decays**

⇒ see M. Gorbahn and M. Diwan talks, this conference