Kaon Physics:
Experimental Status and Perspectives

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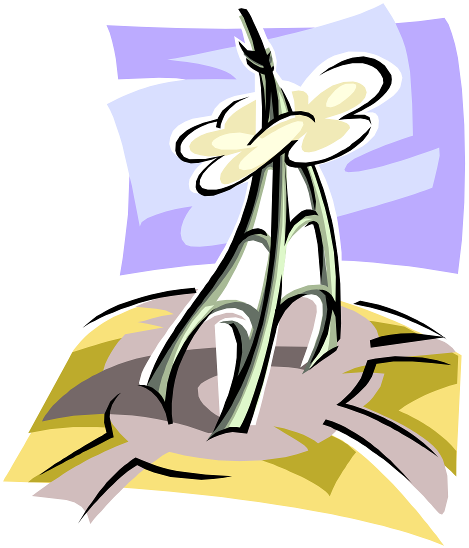


FPCP 2003, Paris – June 5th 2003

Outline

- Re(ε'/ε): the quest for direct CP violation
- Rare K_L decays and CP violation
- Rare K_S decays and CP violation
- T-odd correlations: beyond the SM
- Loop-induced decays and unitarity triangle
- Future projects
- Conclusions ?

Still kaons?

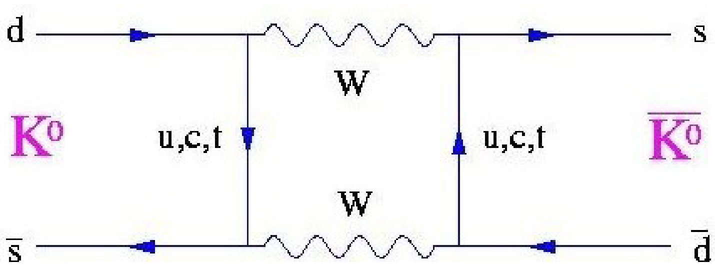
- The "minimal" flavour-laboratory
- *An amazing interferometric system*
- Long lifetime, few decay modes, large mixing
- Both mass and flavour eigenstates accessible
- *All kinds of CP violation present*
- Difficulties in linking measurements to theory (not always!)

Citation: K. Hagiwara *et al.* (Particle Data Group), Phys. Rev. D **66**, 010001 (2002) (URL: http://pdg.lbl.gov)

CP VIOLATION OBSERVED

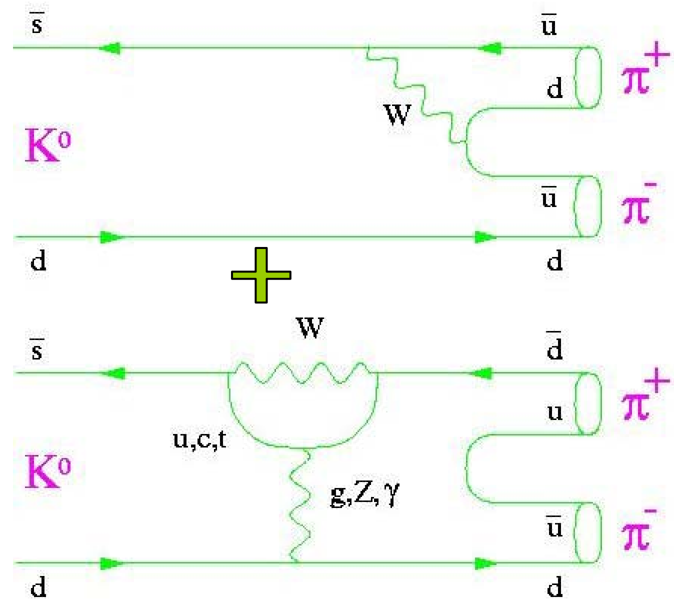
charge asymmetry in $K^0_{\ell 3}$ decays	
δ_L = weighted average of $\delta_L(\mu)$ and $\delta_L(e)$	$(0.327 \pm 0.012)\%$
$\delta_L(\mu) = [\Gamma(\pi^-\mu^+\nu_\mu) - \Gamma(\pi^+\mu^-\overline{\nu}_\mu)]/\text{sum}$	$(0.304 \pm 0.025)\%$
$\delta_L(e) = [\Gamma(\pi^-e^+\nu_e) - \Gamma(\pi^+e^-\overline{\nu}_e)]/\text{sum}$	$(0.333 \pm 0.014)\%$
parameters for $K^0_L \to 2\pi$ decay	
$\lvert\eta_{00}\rvert = \lvert A(K^0_L \to 2\pi^0) / A(K^0_S \to 2\pi^0)\rvert$	$(2.274 \pm 0.017) \times 10^{-3}$
$\lvert\eta_{+-}\rvert = \lvert A(K^0_L \to \pi^+\pi^-) / A(K^0_S \to \pi^+\pi^-)\rvert$	$(2.286 \pm 0.017) \times 10^{-3}$
$\mathrm{Re}(\epsilon'/\epsilon) = (1-\lvert\eta_{00}/\eta_{+-}\rvert)/3$	[e] $(1.8 \pm 0.4) \times 10^{-3}$ $(S = 2.3)$
First ϕ_{+-} or ϕ_{00} assumes CPT, second does not.	
ϕ_{+-}, phase of η_{+-}	$(43.51 \pm 0.06)^\circ$
ϕ_{+-}, phase of η_{+-}	$(43.4 \pm 0.7)^\circ$
ϕ_{00}, phase of η_{00}	$(43.51 \pm 0.06)^\circ$
ϕ_{00}, phase of η_{00}	$(43.2 \pm 1.0)^\circ$
CP asymmetry A in $K_L \to \pi^+\pi^-e^+e^-$	$(13.6 \pm 2.8)\%$
β_{CP} from $K_L \to e^+e^-e^+e^-$	-0.23 ± 0.09
γ_{CP} from $K^0_L \to e^+e^-e^+e^-$	-0.09 ± 0.09
parameters for $K^0_L \to \pi^+\pi^-\gamma$ decay	
$\lvert\eta_{+-\gamma}\rvert = \lvert A(K^0_L \to \pi^+\pi^-\gamma, CP \text{ violating})/A(K^0_S \to \pi^+\pi^-\gamma)\rvert$	$(2.35 \pm 0.07) \times 10^{-3}$
$\phi_{+-\gamma}$ = phase of $\eta_{+-\gamma}$	$(44 \pm 4)^\circ$
$\Gamma(K^0_L \to \pi^+\pi^-)/\Gamma_{\text{total}}$	$(2.084 \pm 0.032) \times 10^{-3}$ $(S = 1.1)$
$\Gamma(K^0_L \to \pi^0\pi^0)/\Gamma_{\text{total}}$	$(9.42 \pm 0.19) \times 10^{-4}$ $(S = 1.1)$
Parameters for $B^0 \to J/\psi K^0_S$	
$\sin(2\beta)$	0.79 ± 0.14 $(S = 1.3)$

The Quest for Direct CP Violation



Indirect CP violation in the mixing: ε

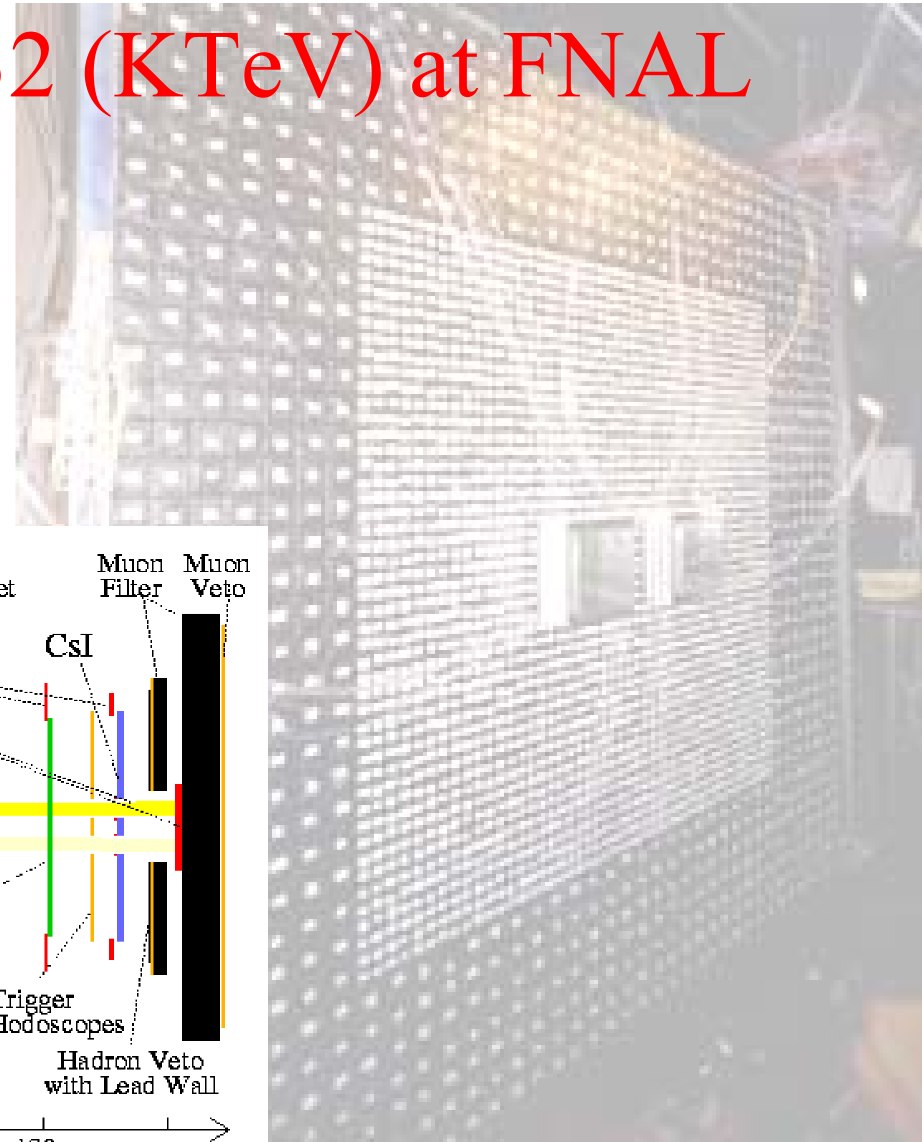
Direct CP violation in the decay: ε'



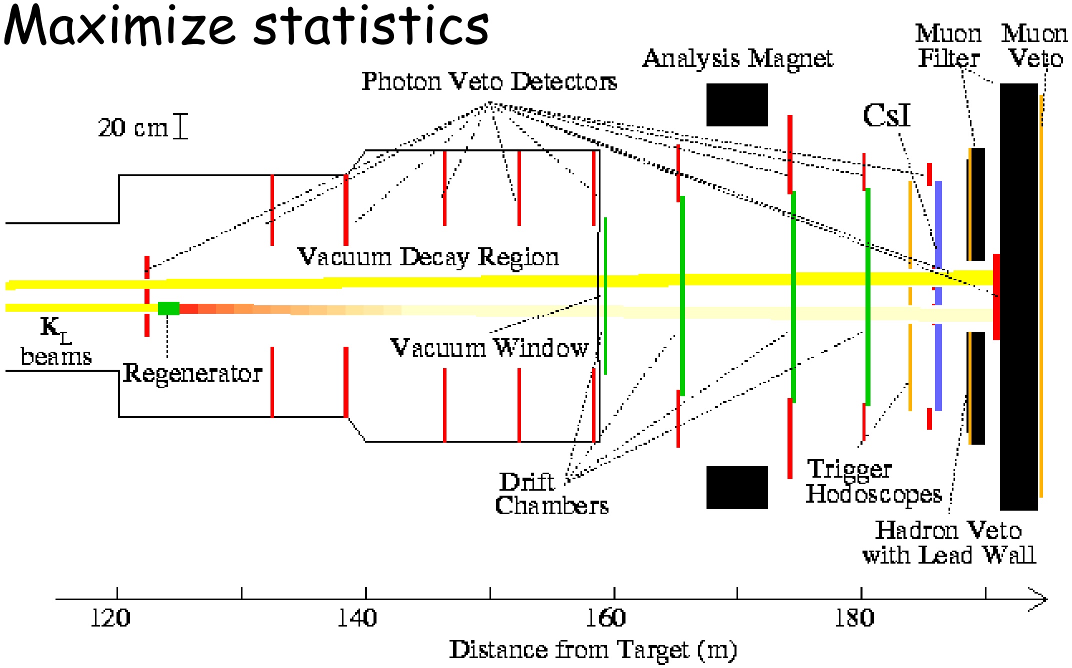
A fascinating 30-year long enterprise: *"Is CP violation a peculiarity of kaons? Is it induced by a new superweak interaction?"*

KTEV
Kaons at the Tevatron

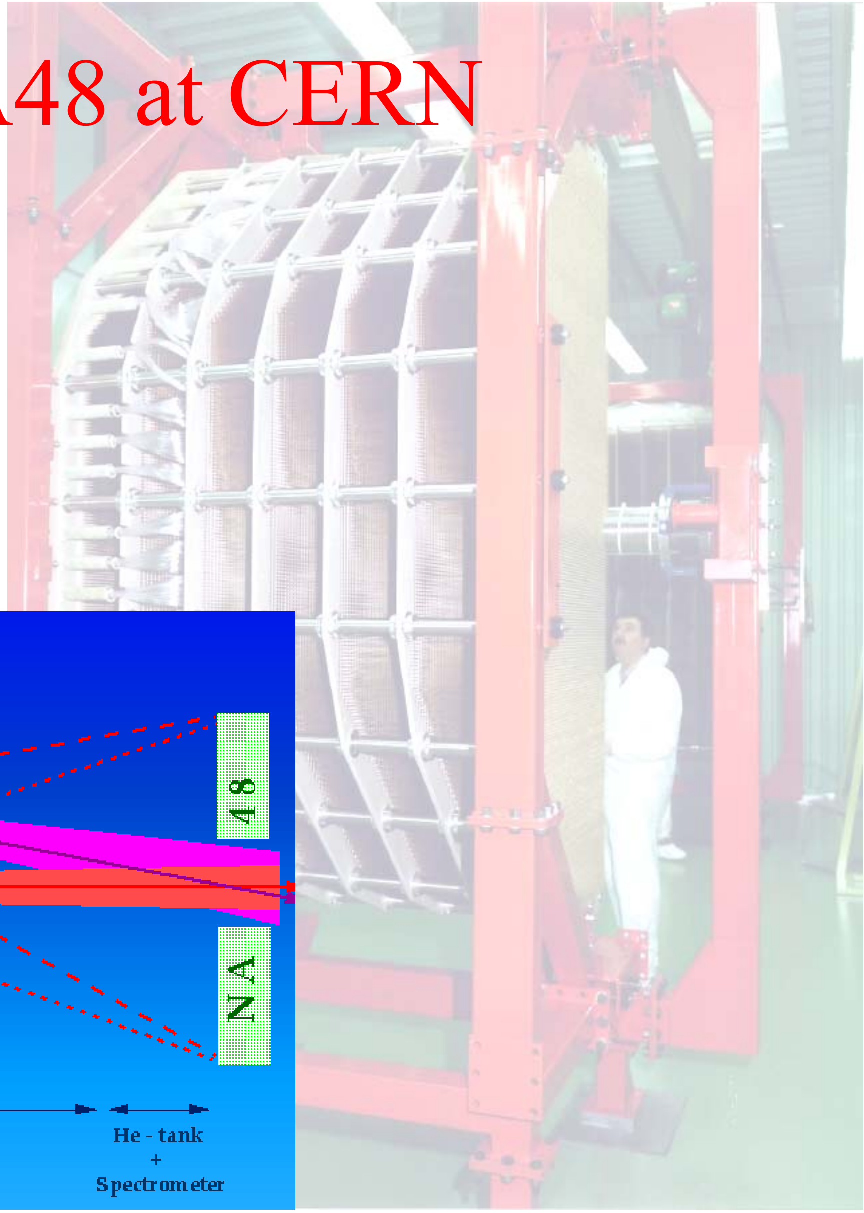
E832 (KTeV) at FNAL



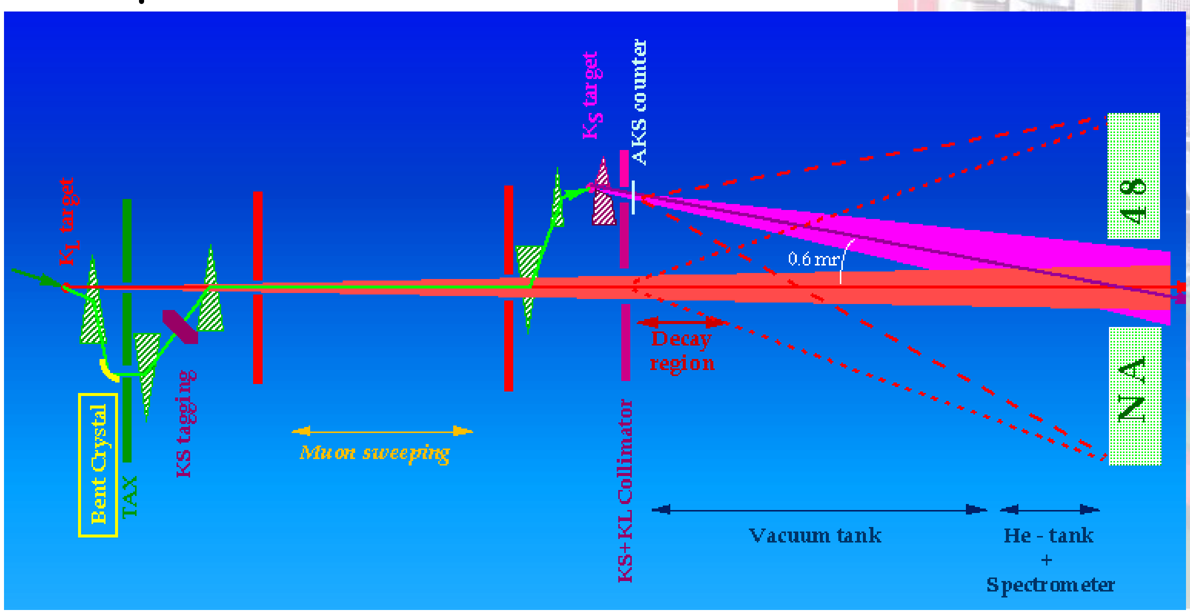
Double K_L beams (<p>=70 GeV/*c*)
Regenerator for K_S
Pure CsI calorimeter
Tagging by event position
MC acceptance correction
Maximize statistics



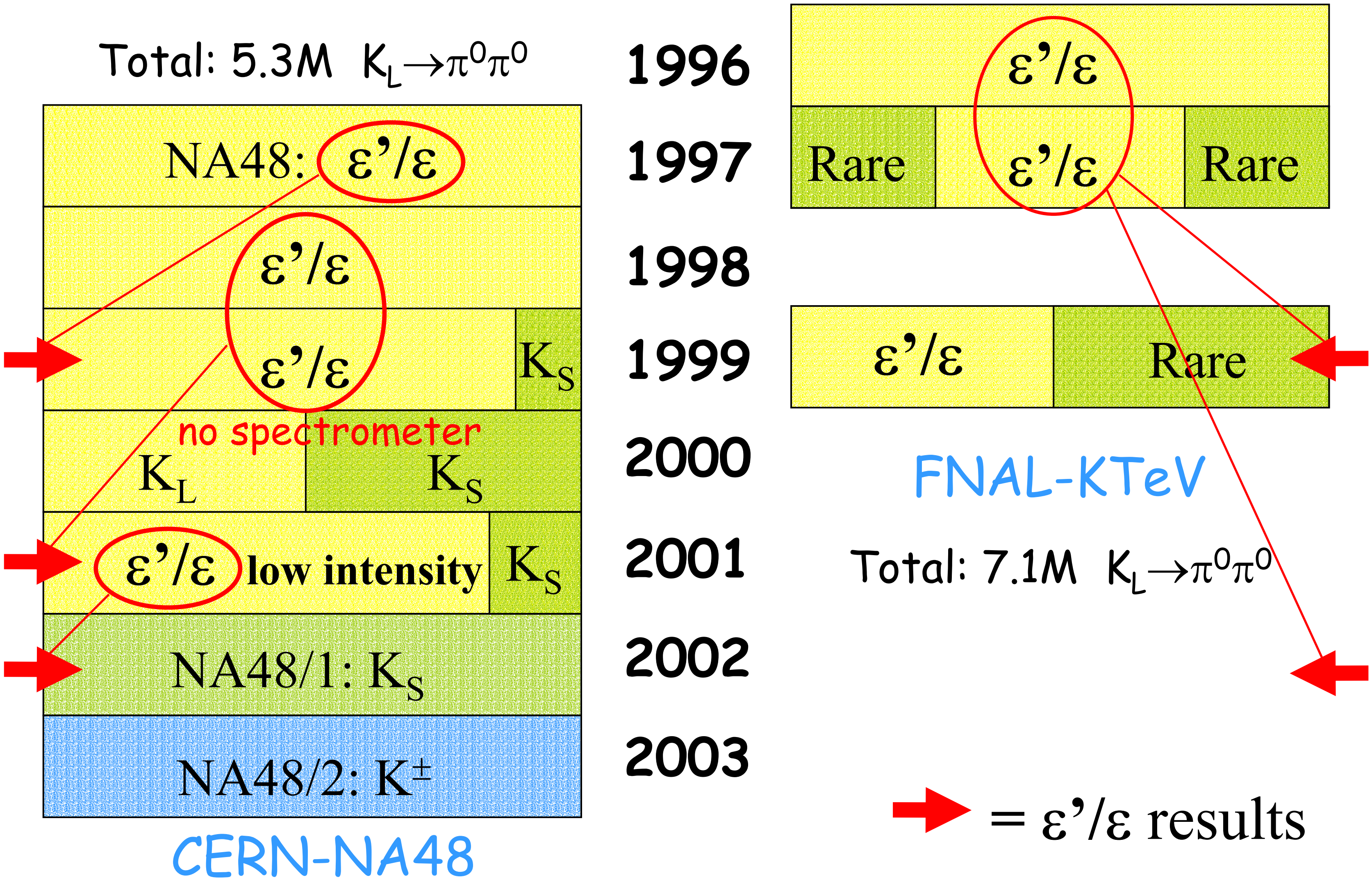
NA48 at CERN



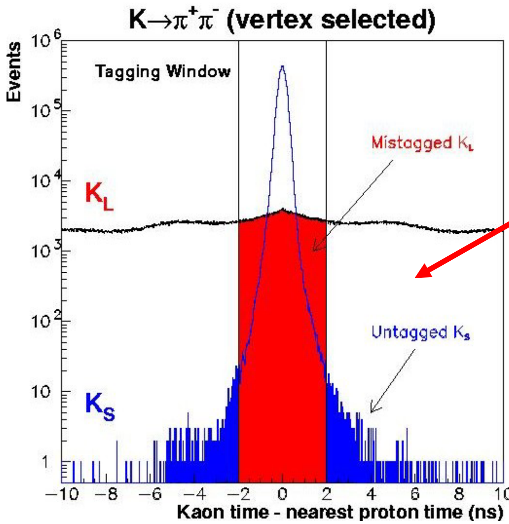
- Simultaneous near/far targets
- Converging beams (<p>=100 GeV/c)
- Liquid Kr calorimeter
- Tagging by time-of-flight
- Lifetime weighting to minimize acceptance correction



Data Taking Periods

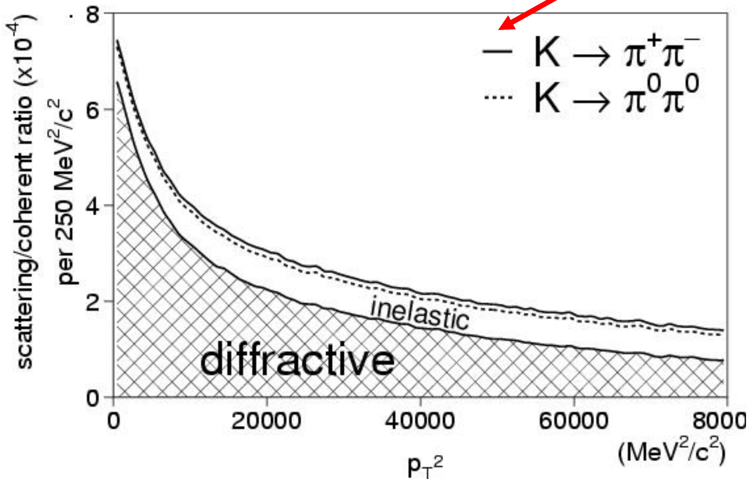


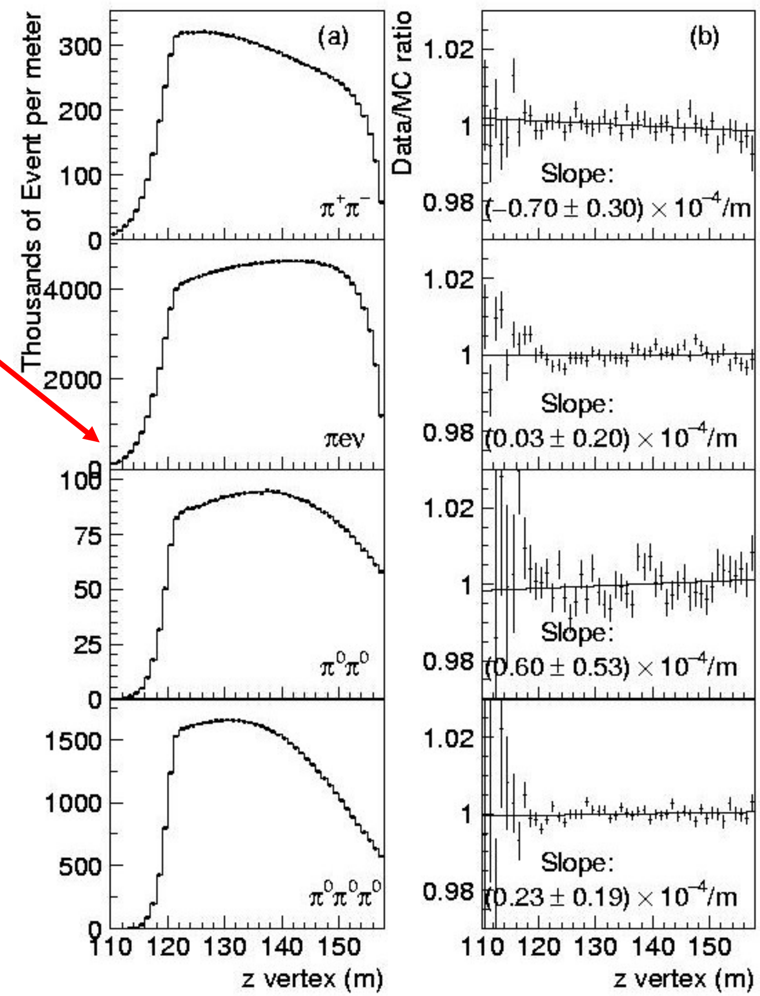
Ways towards direct CPV



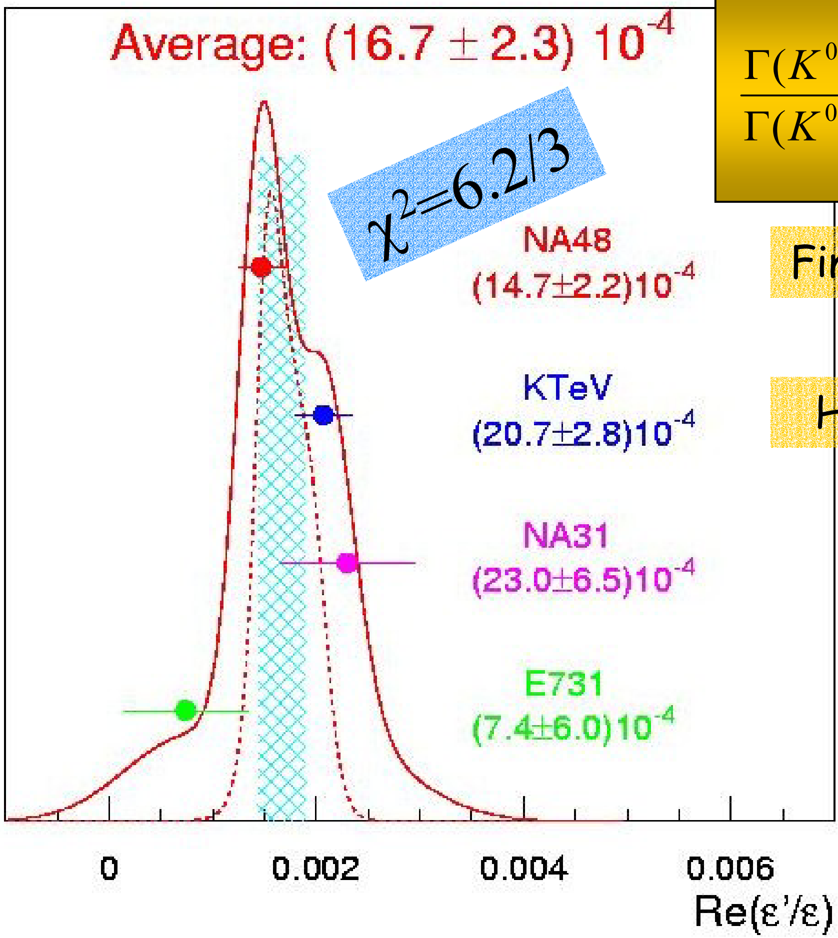
NA48:
TOF tagging

KTeV: MC
incoherent
regeneration





Re(ε'/ε) Results



$$\frac{\Gamma(K^0 \to \pi^+\pi^-) - \Gamma(\overline{K}^0 \to \pi^+\pi^-)}{\Gamma(K^0 \to \pi^+\pi^-) + \Gamma(\overline{K}^0 \to \pi^+\pi^-)} = (5.04 \pm 0.82) \times 10^{-6}$$

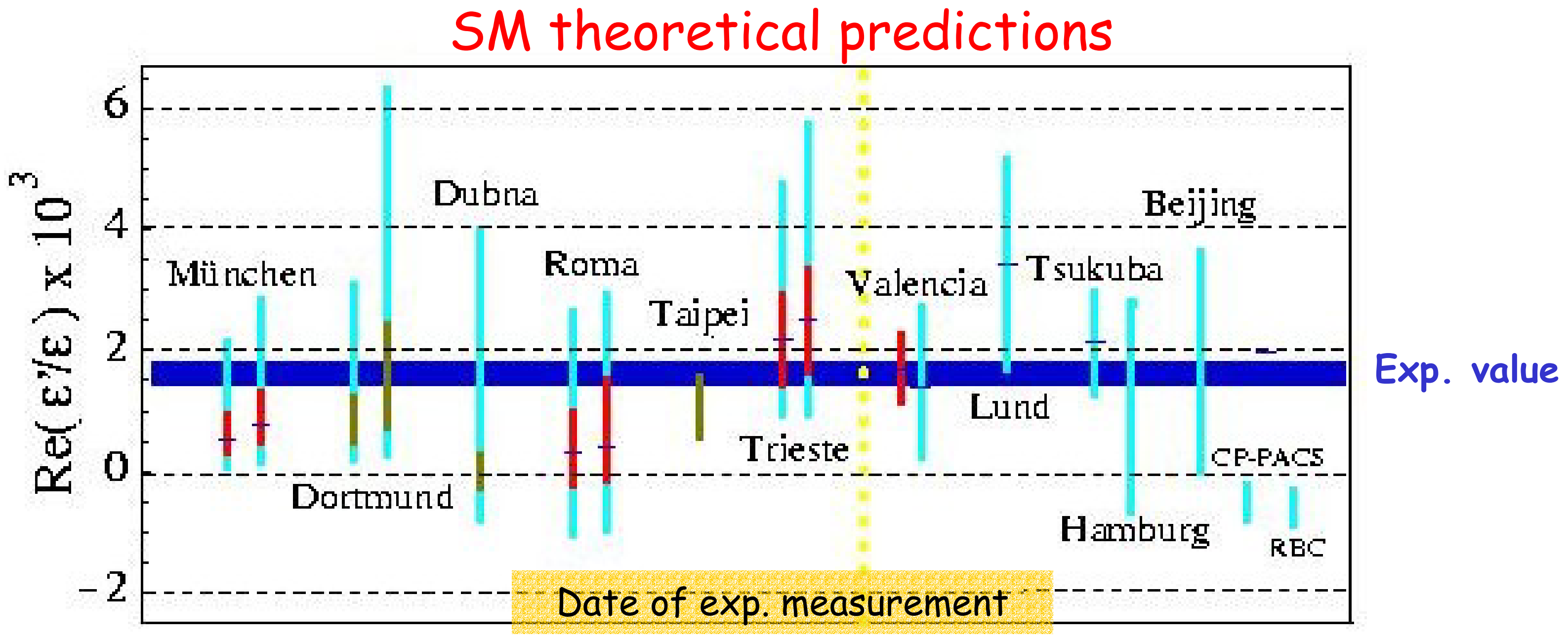
Final result (1997-2001)

Half statistics (1997)

Direct CP violation proved at >7σ level... after 36 years!

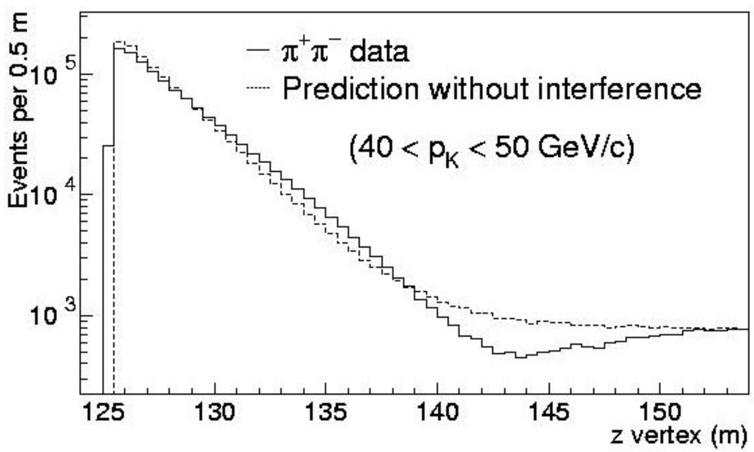
Wait for further results from KTeV and KLOE

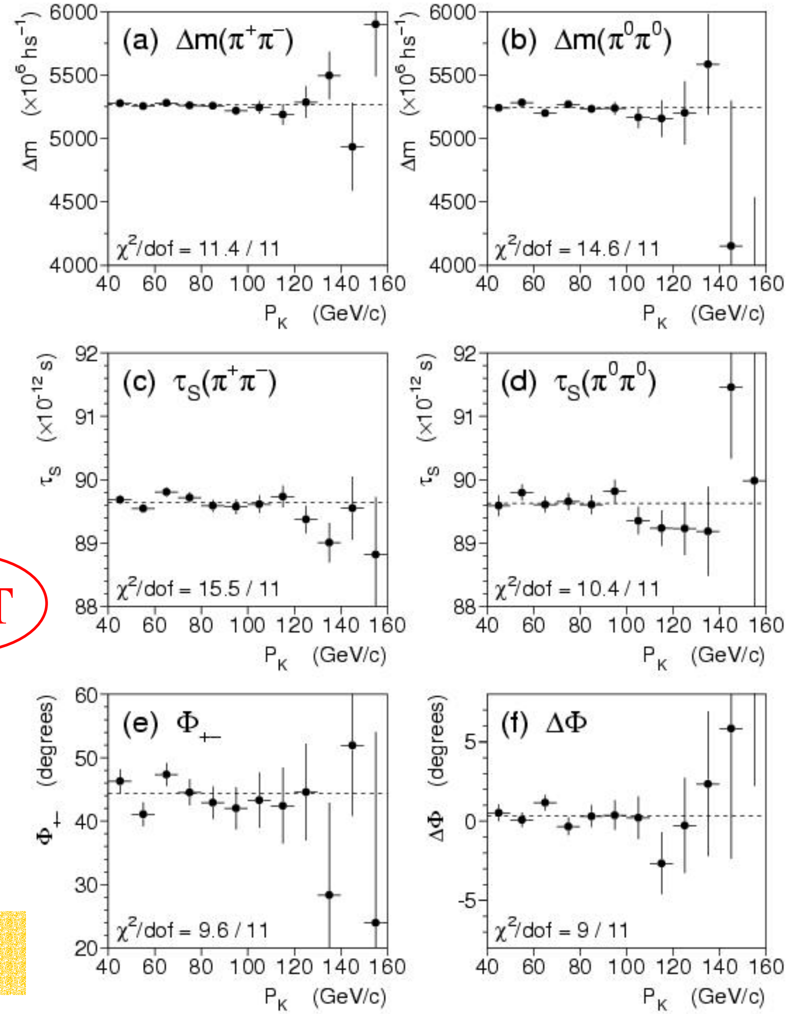
Re(ε'/ε) and the SM



Despite huge efforts, ε'/ε not yet computed reliably
Measured value is roughly compatible with the SM
Expect improvements from lattice

Other kaon Parameters





KTeV

$\Delta m = (5261 \pm 15) \times 10^6\ \hbar\ s^{-1}$

$\tau_S = (89.65 \pm 0.07) \times 10^{-12}$ s

CPT

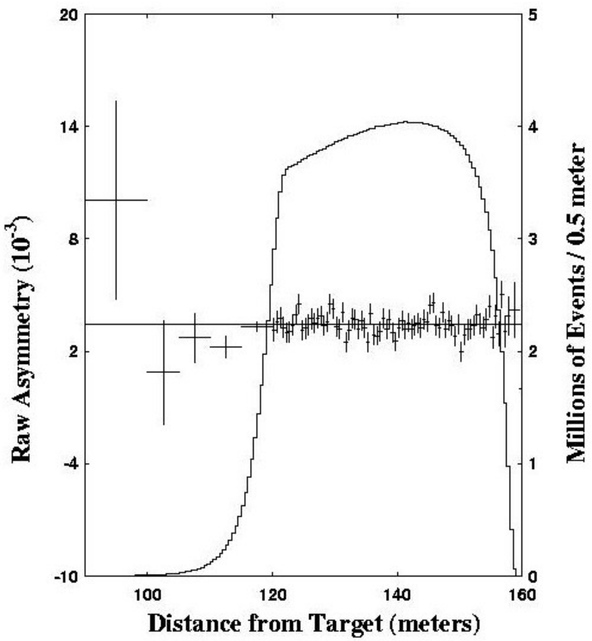
$\phi_{+-} - \phi_{SW} = (0.61 \pm 1.19)^o$

$\phi_{00} - \phi_{+-} = (0.39 \pm 0.50)^o$

$\mathrm{Im}(\varepsilon'/\varepsilon) = (-22.9 \pm 29.1) \times 10^{-4}$

NA48: $\tau_S = (89.60 \pm 0.07) \times 10^{-12}$ s

Semileptonic Charge Asymmetry



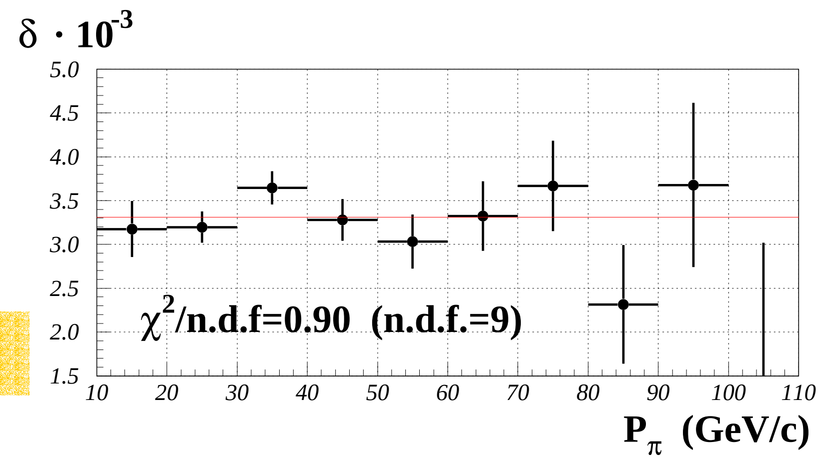
Measure of indirect CP violation in the mixing (ε) and limits on CPT and $\Delta S=\Delta Q$

Preliminary

NA48

2×10^8 events in 2001 run

$\delta_L(e) = (3.317 \pm 0.070 \pm 0.072) \times 10^{-3}$



KTeV

3×10^8 events in 2001 run

$\delta_L(e) = (3.322 \pm 0.058 \pm 0.047) \times 10^{-3}$

CPT test using $\pi\pi$ data: $\mathrm{Re}(y+x\_/2+a) = (-5 \pm 31) \times 10^{-6}$

KLOE at DAΦNE

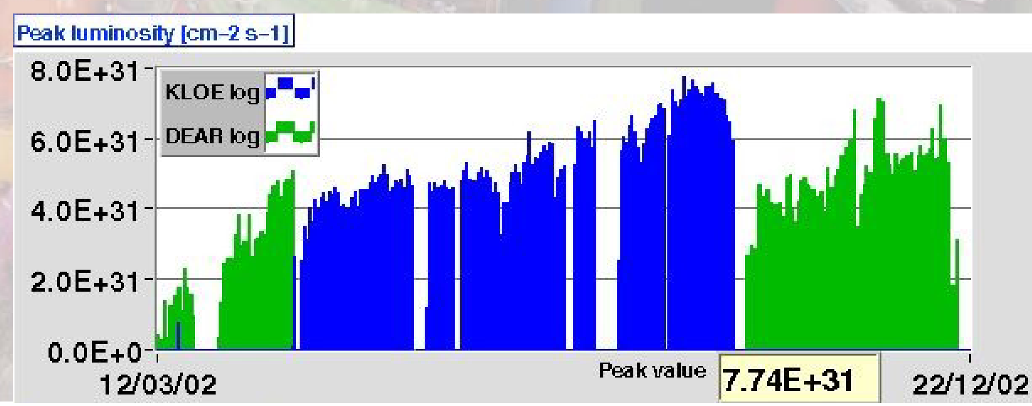
$\Gamma(K_S \to \pi^+\pi^-(\gamma))/\Gamma(K_S \to \pi^0\pi^0) = (2.236 \pm 0.003 \pm 0.015)$

from which $\delta_0 - \delta_2 \cong (48 \pm 3)°$ (2000 data)

$BR(K^\pm \to \pi^\pm\pi^0\pi^0) = (1.807 \pm 0.008 \pm 0.018)\%$

Good prospects for rare K_S decays, interferometry, new IR

Peak luminosity:
8×10^{31} cm^{-2} s^{-1} in 2002
Goal: 5×10^{32} cm^{-2} s^{-1}
500 pb^{-1} (1.5×10^9 ϕ)
collected so far



KLOE results

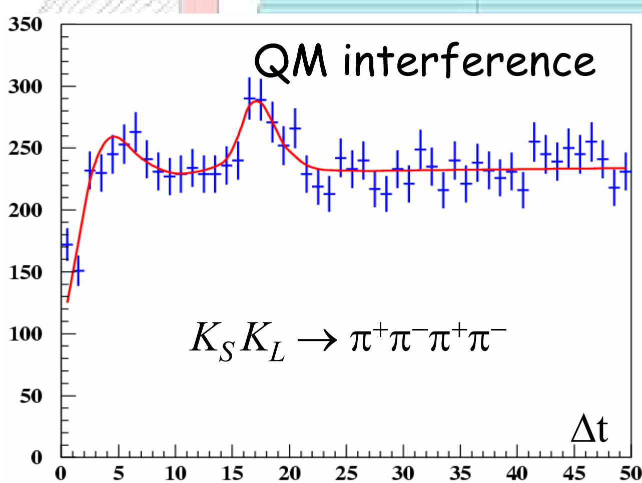
Using K_L-crash tagging of K_S:

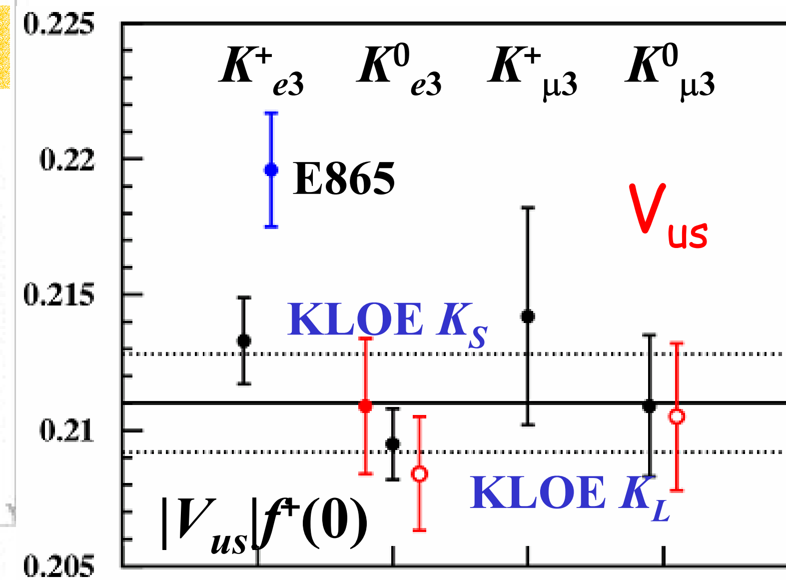
Preliminary (2001 data)

$\delta_S = (1.9 \pm 1.7 \pm 0.6) \times 10^{-2}$ K_S semileptonic charge asymmetry

$\mathrm{Re}(x_+) = (3.3 \pm 5.2 \pm 3.5) \times 10^{-3}$ $\Delta S = \Delta Q$ in CPT-conserving amplitudes

$\mathrm{BR}(K_S \to \pi e \nu) = (6.81 \pm 0.12 \pm 0.10) \times 10^{-4}$





E799-II (KTeV): Rare K_L decays

Intense KL flux allows sensitive searches; checks of χPT

$K_L \to e^+e^-\gamma$ (1997, 93K events – norm. $\pi^0\pi^0\pi^0_D$):

Preliminary $BR(K_L \to e^+e^-\gamma) = (10.13 \pm 0.04 \pm 0.06 \pm 0.29_{norm}) \times 10^{-6}$

$K_L \to e^+e^- e^+e^-$ (1997+1999, 1K events – norm $\pi^0\pi^0_D\pi^0_D$):

Preliminary $BR(K_L \to e^+e^-e^+e^-) = (4.07 \pm 0.12 \pm 0.11 \pm 0.16_{norm}) \times 10^{-8}$

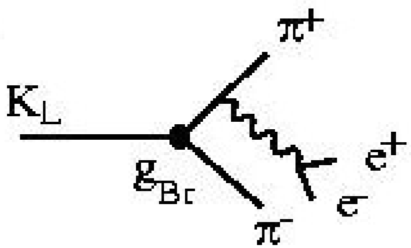
no CP violation found in decay plane asymmetry

$K_L \to e^+e^-\mu+\mu-$ (1997+1999, 132 events – norm $\pi^+\pi^-\pi^0_D$):

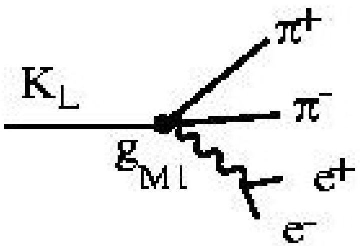
$BR(K_L \to e^+e^-\mu^+\mu^-) = (2.69 \pm 0.24 \pm 0.12) \times 10^{-9}$

New results expected soon with full 1997+1999 data sample:
$K_L \to e^+e^- e^+e^-$ and $K_L \to e^+e^-\gamma$ form factors, $K_L \to \pi^+\pi^- e^+e^-$ update

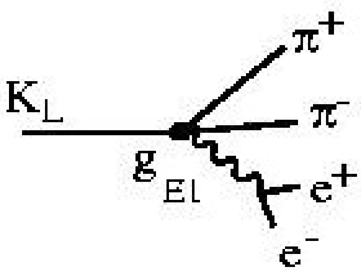
$K_{L,S} \to \pi^+\pi^-e^+e^-$: why?



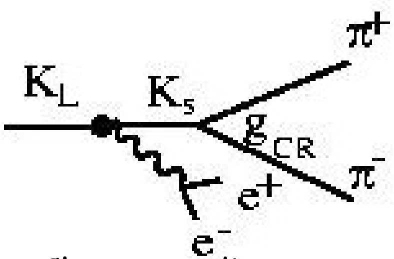
CPV inner bremsstrahlung



CPC direct emission



CPV direct emission



Charge radius

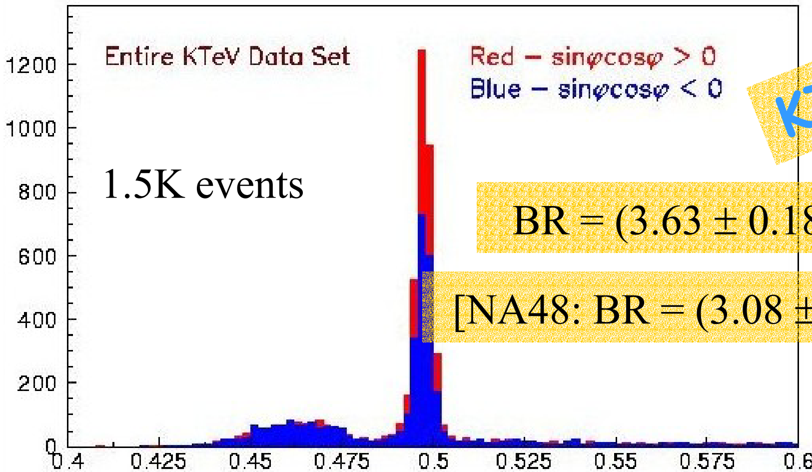
For K_L: interference gives indirect CP-violating asymmetry in the orientation of $\pi^+\pi^-$ and e^+e^- decay planes

Easier access to polarization asymmetry in $K \to \pi\pi\gamma$

Large ($\approx$ 14%) asymmetries predicted

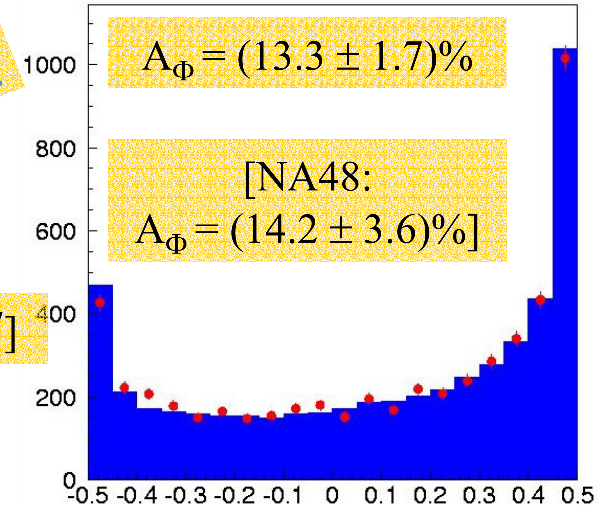
$K_{L,S} \to \pi^+\pi^-e^+e^-$

KTeV: K_L



BR = $(3.63 \pm 0.18) \times 10^{-7}$

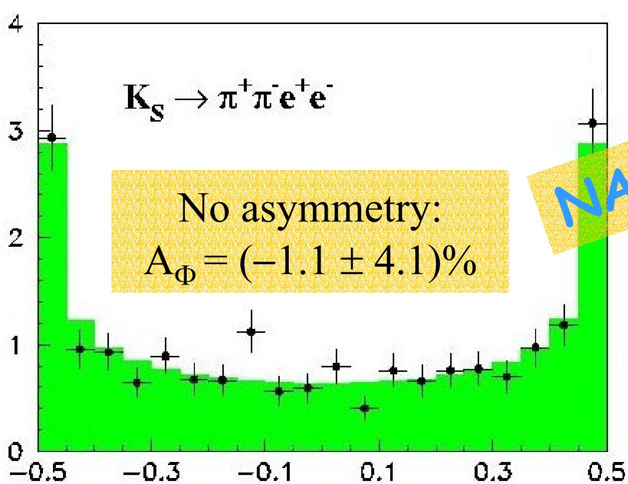
[NA48: BR = $(3.08 \pm 0.2) \times 10^{-7}$]



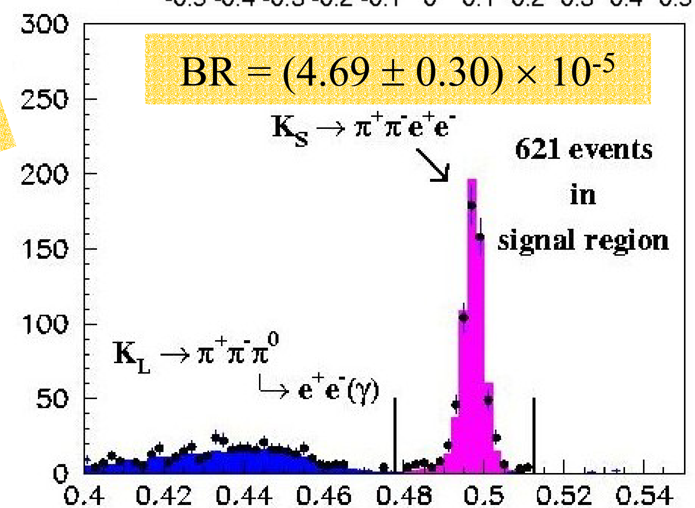
$A_\Phi = (13.3 \pm 1.7)\%$

[NA48: $A_\Phi = (14.2 \pm 3.6)\%$]

NA48: K_S, K_L

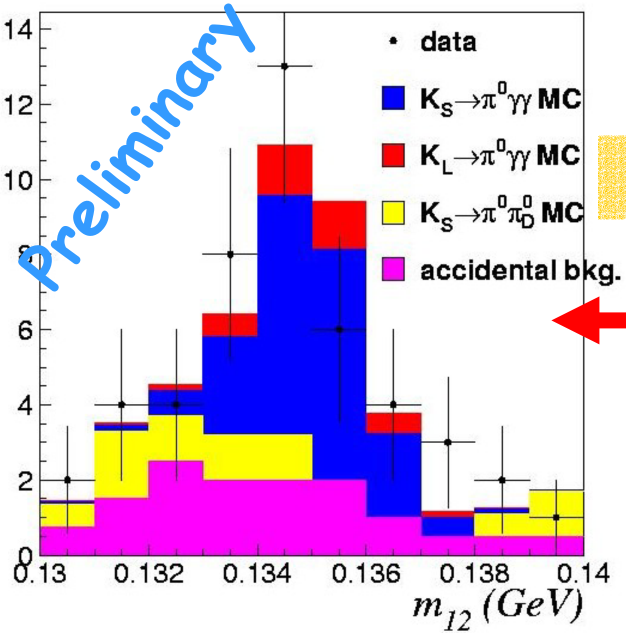


No asymmetry: $A_\Phi = (-1.1 \pm 4.1)\%$



BR = $(4.69 \pm 0.30) \times 10^{-5}$

NA48/1 – Rare KS decays

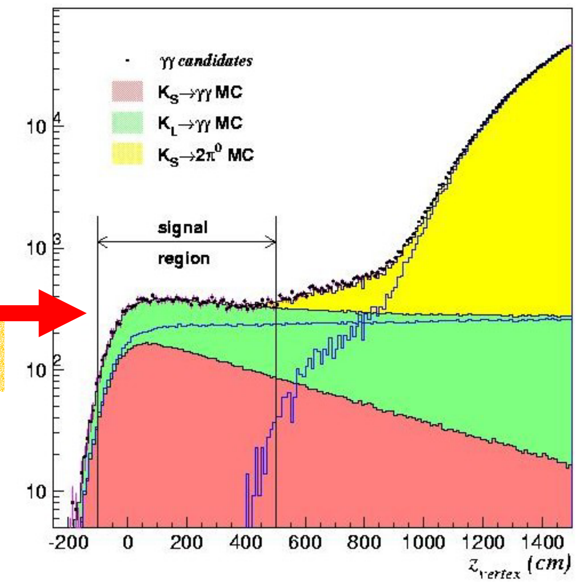


First measurement of $K_S \to \pi^0\gamma\gamma$
31 events, 13.6 background

$$BR(K_S \to \pi^0\gamma\gamma)_{z>0.2} = (4.9 \pm 1.6 \pm 0.8) \times 10^{-8}$$

30% higher than χPT prediction

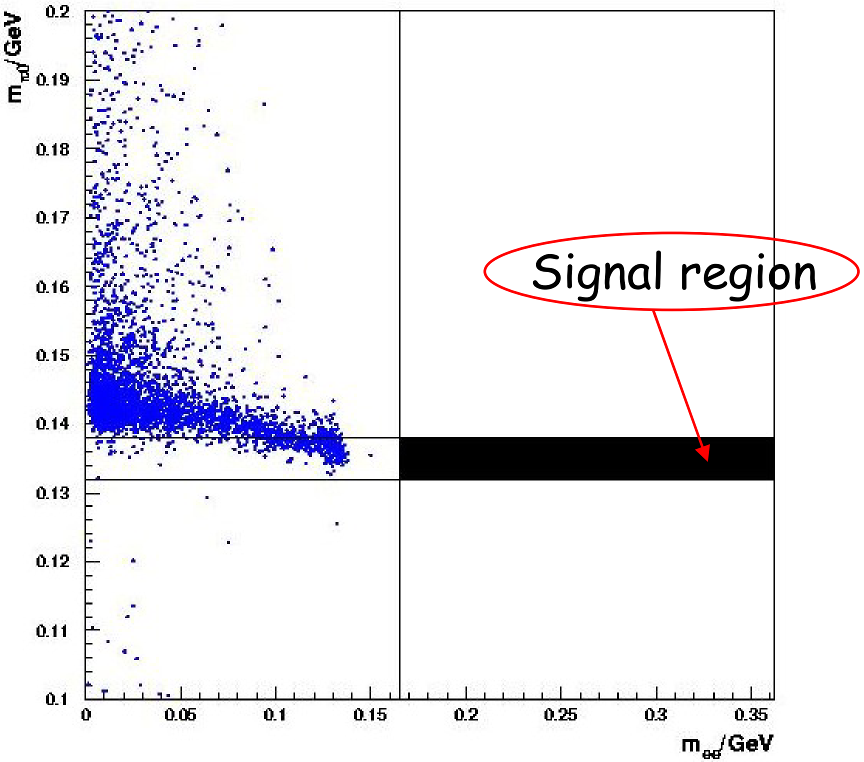
Not yet sensitive to chiral structure of weak vertex



$$BR(K_S \to \gamma\gamma) = (2.78 \pm 0.02 \pm 0.04) \times 10^{-6}$$

For both: first contribution at $O(p^4)$ in χPT
Indications of large $O(p^6)$ terms

NA48/1 - Search for $K_S \to \pi^0 e^+ e^-$



Determines indirect CP-violating contribution to $K_L \to \pi^0 e^+ e^-$ decay

Published limit from 1999 data:

$$BR(K_S \to \pi^0 e^+ e^-) < 1.4 \times 10^{-7}$$

(90% CL)

2001 K_S run data analyzed - Result available very soon

Search for $K_S \to 3\pi^0$

$$\eta_{000} = \frac{A(K_S \to 3\pi^0)}{A(K_L \to 3\pi^0)}$$

Expectation ≈ ε
Im (η_{000}) sensitive to direct CPV

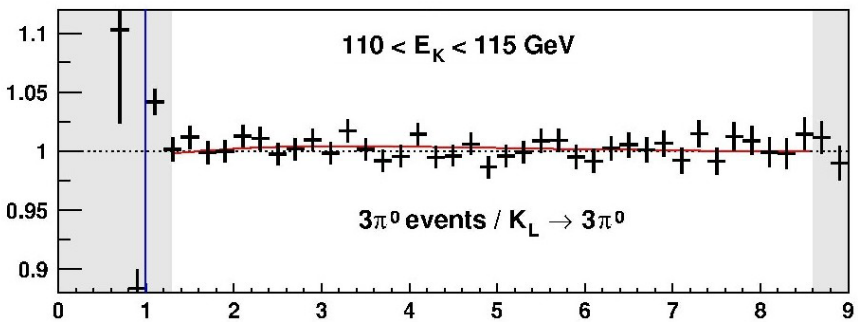
CPLEAR (1999)
$\mathrm{Re}(\eta_{000}) = 0.18 \pm 0.15$
$\mathrm{Im}(\eta_{000}) = 0.15 \pm 0.20$

SND, Novosibirsk (1999)
$BR(K_S \to 3\pi^0) < 1.4\times10^{-5}$

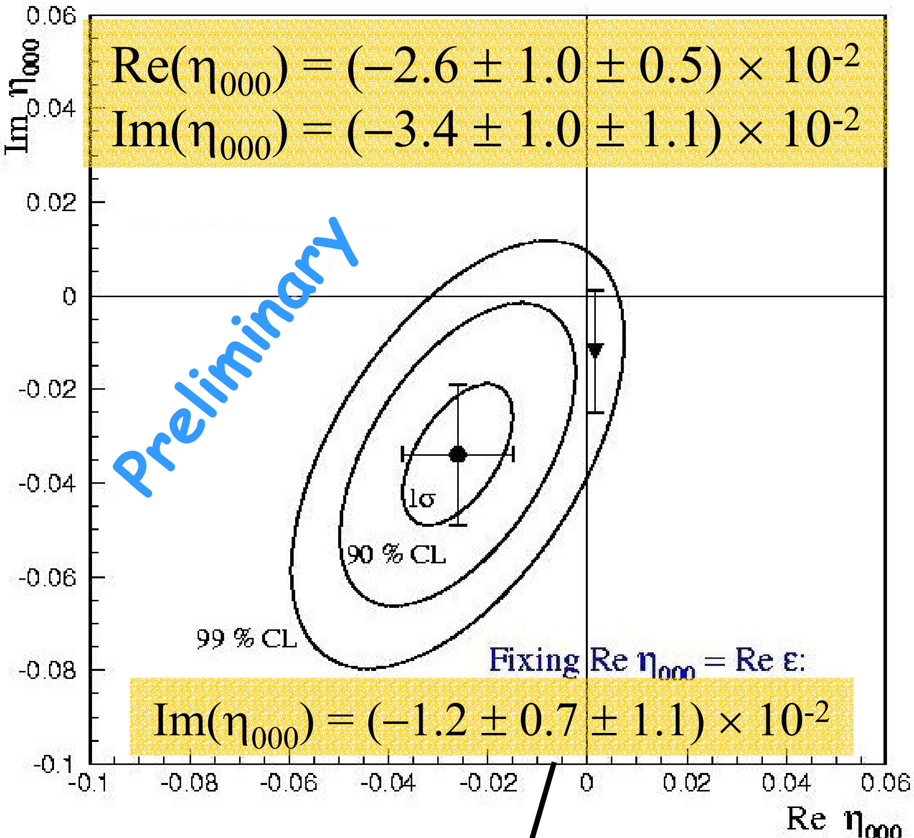
$$I_{3\pi^0}(t) \propto e^{-\Gamma_L t} + |\eta_{000}|^2 e^{-\Gamma_S t} +$$
$$2D(p)\left[\mathrm{Re}(\eta_{000})\cos(\Delta m t) - \mathrm{Im}(\eta_{000})\sin(\Delta m t)\right]e^{-(\Gamma_S+\Gamma_L)t/2}$$

Hadron machines: search for interference term

NA48/1: $K_S \to 3\pi^0$



- Data from 2000 run
- Use near-target data: 6.5M $3\pi^0$ events
- Normalize to far-target data: 155M $3\pi^0$ events
- Correct residual acceptance difference with MC



$BR(K_S \to 3\pi^0) < 1.4\times10^{-6}$ (90% CL)

CPT Test From $K_S \to 3\pi^0$

Bell-Steinberger relation (unitarity) connects indirect CPT violation δ to CP-violating decays

$$(1 + i\tan\phi_{SW})\left[\mathrm{Re}(\varepsilon) - i\,\mathrm{Im}(\delta)\right] = \sum_f \alpha_f$$

$$\tan\phi_{SW} = \frac{2\Delta m}{\Gamma_S - \Gamma_L} \qquad \alpha_f = \left(1/\Gamma_S\right) A(K_L \to f)\, A^*(K_S \to f)$$

Largest contribution to the error from $f = 3\pi^0$

After NA48/1: $\mathrm{Im}(\delta) = (-1.2 \pm 3.0) \times 10^{-5}$

Assuming no CPT violation in the decay:

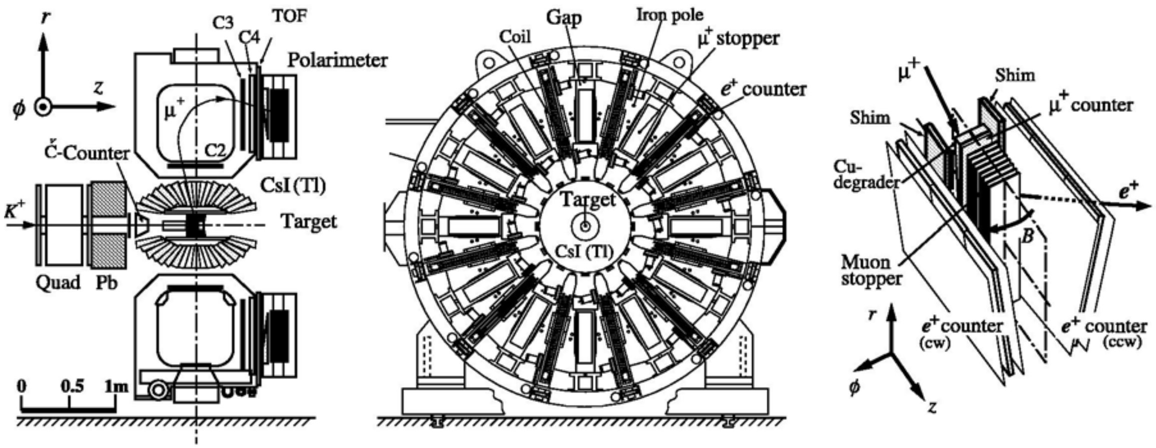
$$m(K^0) - m(\overline{K}^0) = (-1.7 \pm 4.2) \times 10^{-19}\ \mathrm{GeV}/c^2$$

Preliminary

KEK E246: T-violation in $K^+ \to \pi^0 \mu^+ \nu$

Search for $P_T(\mu)$ orthogonal to $(\pi\mu)$ decay plane

FSI in SM give $P_T < 10^{-5}$: probe of New Physics



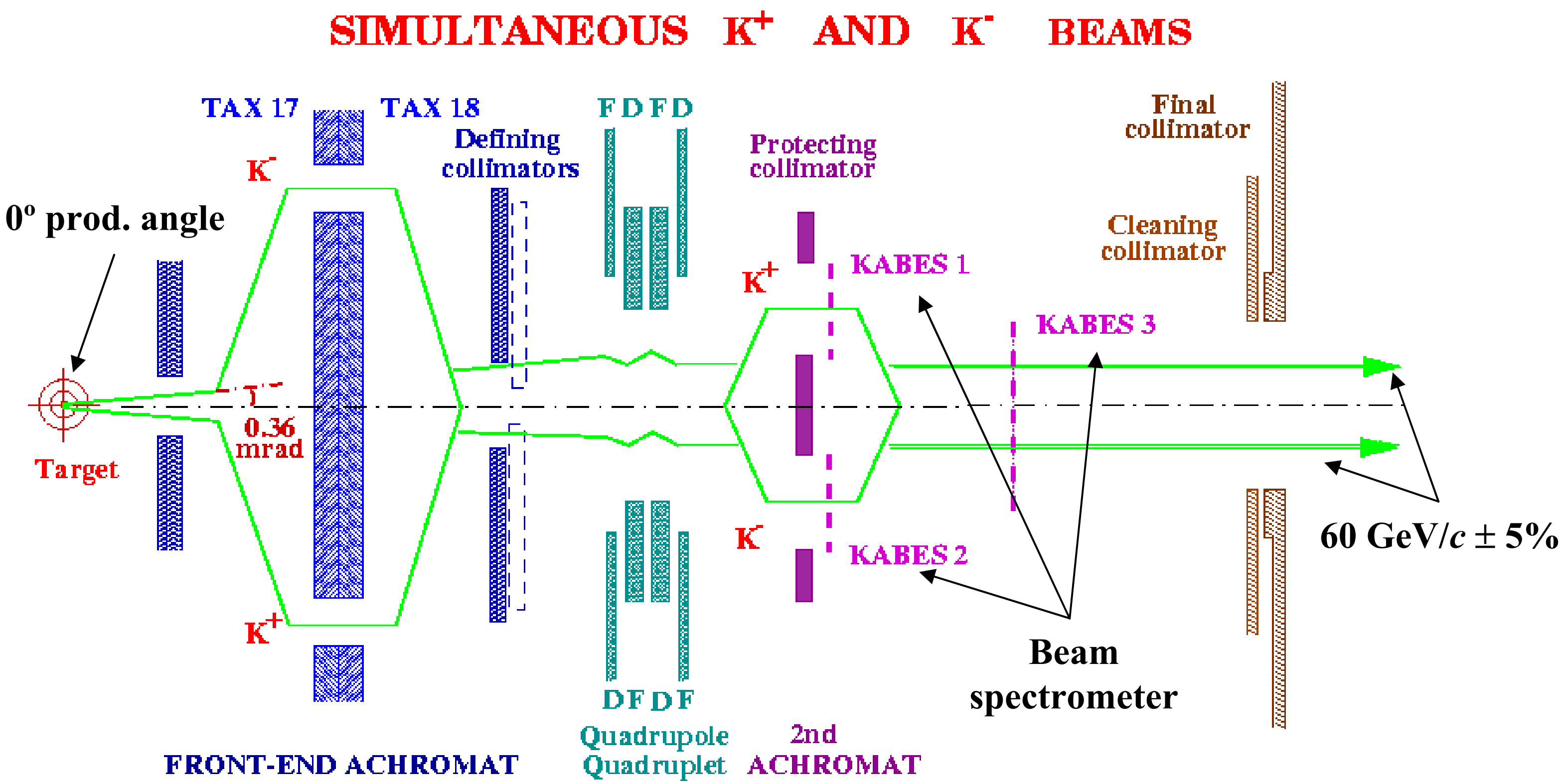
660 MeV/c kaons stopped in absorber

Combined result from 8.3M decays (1996-2000):

$$P_T(\mu) = (-1.12 \pm 2.17 \pm 0.9) \times 10^{-3}$$

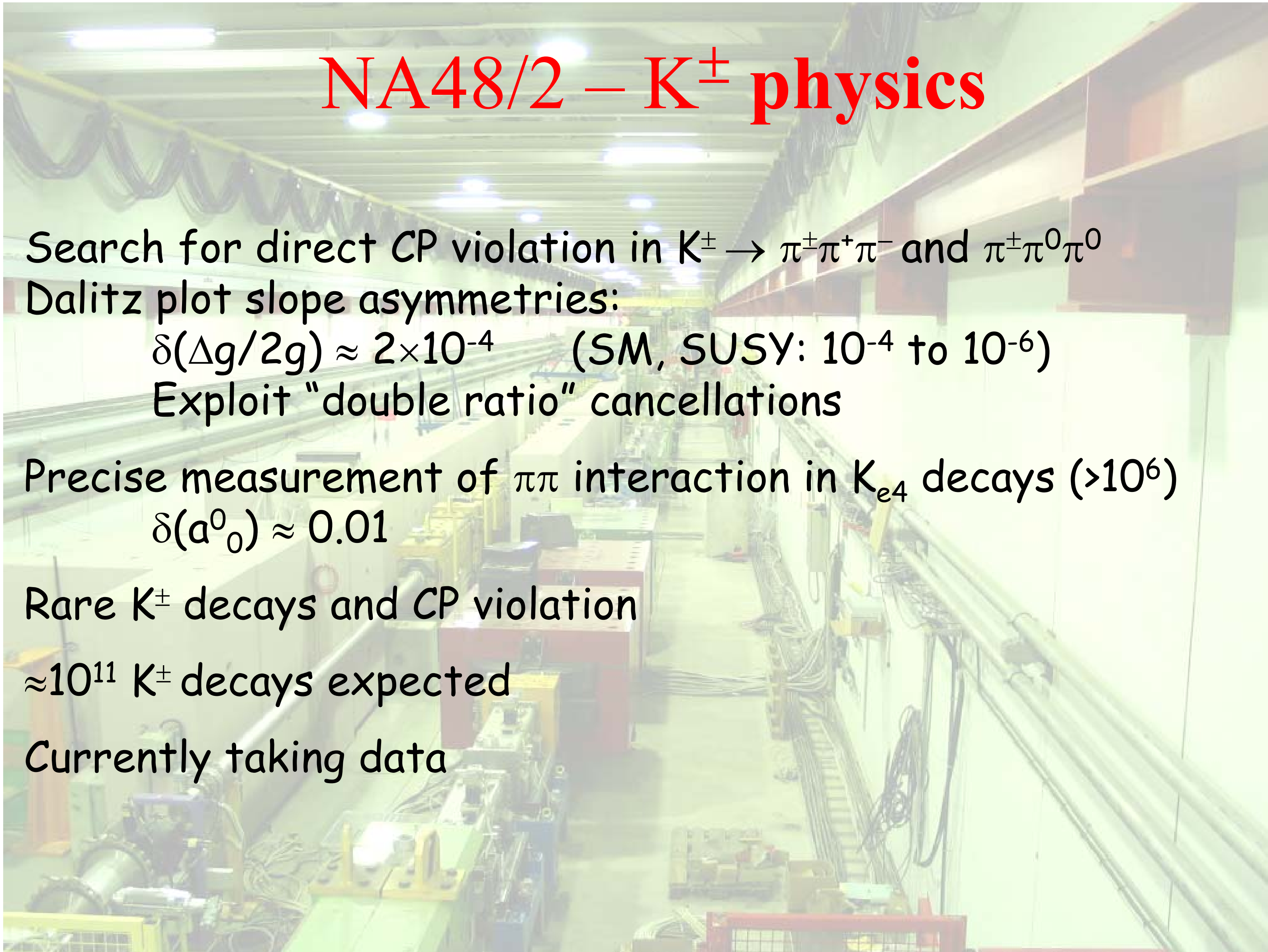
LOI to reach 10^{-4} accuracy at J-PARC

NA48/2 – $K^{\pm}$ decays



New simultaneous K+ and K- narrow band beam

Kaon momentum spectrometer



NA48/2 – $K^{\pm}$ **physics**

Search for direct CP violation in $K^{\pm} \to \pi^{\pm}\pi^{+}\pi^{-}$ and $\pi^{\pm}\pi^{0}\pi^{0}$

Dalitz plot slope asymmetries:

$\delta(\Delta g/2g) \approx 2\times10^{-4}$ (SM, SUSY: 10^{-4} to 10^{-6})

Exploit "double ratio" cancellations

Precise measurement of $\pi\pi$ interaction in K_{e4} decays ($>10^{6}$)

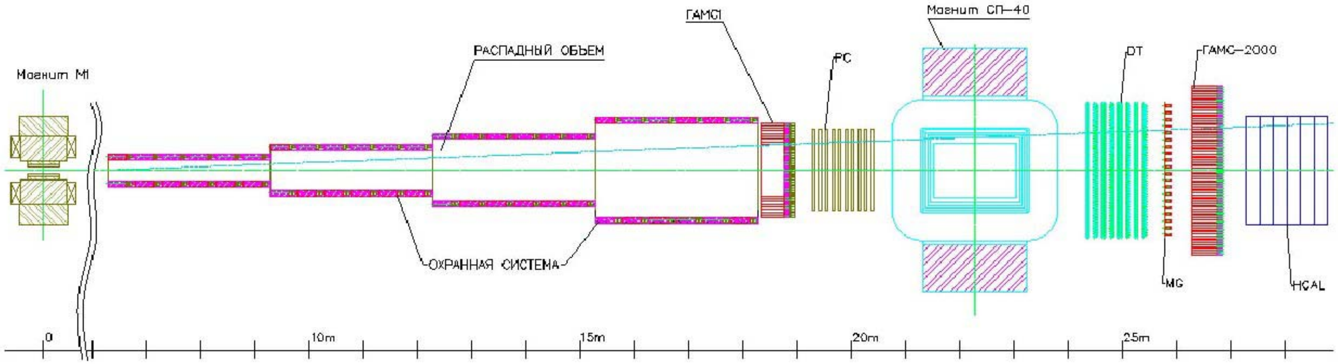
$\delta(a^{0}_{0}) \approx 0.01$

Rare $K^{\pm}$ decays and CP violation

$\approx 10^{11}$ $K^{\pm}$ decays expected

Currently taking data

OKA @ Protvino - $K^{\pm}$

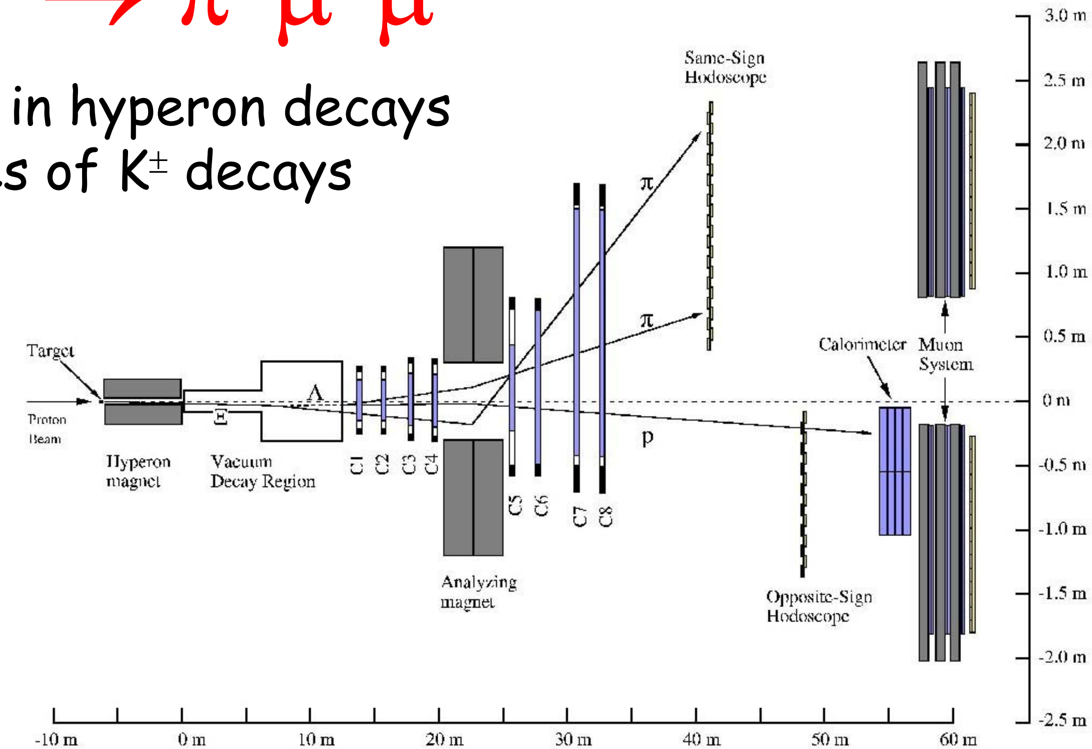


New RF-separated beam at U-70 PS in construction
15 GeV/c kaons, alternating K+ or K-
Magnetic detector evolved from ISTRA+, GAMS
In preparation, expected 2004
Measurement of 3π Dalitz plot asymmetries @ 1×10^{-4}
T-odd correlations, search for New Physics in K_{l2} decays

HyperCP: $K^{\pm} \to \pi^{\pm}\mu^{+}\mu^{-}$

Main goal: CP violation in hyperon decays
Collected large samples of $K^{\pm}$ decays

$K^{\pm} \to \pi^{\pm}\mu^{+}\mu^{-}$: FCNC
GIM-suppressed loops
Dominated by long-distance effects



Preliminary

From 1997 statistics (≈1/5):

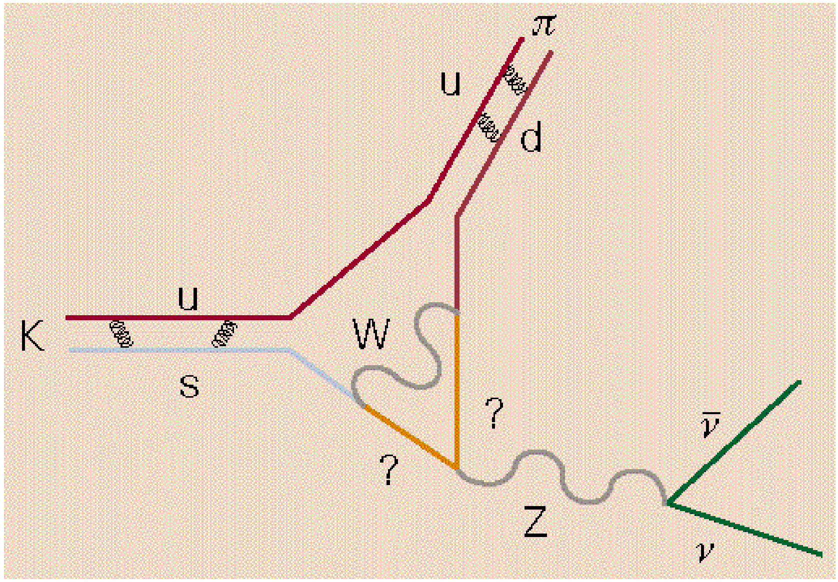
$$BR(K^{\pm} \to \pi^{\pm}\mu^{+}\mu^{-}) = (9.8 \pm 1.0 \pm 0.5) \times 10^{-8}$$

$$A_{\Gamma}(K^{\pm} \to \pi^{\pm}\mu^{+}\mu^{-}) = -0.02 \pm 0.11 \pm 0.04$$

The golden modes: $K \to \pi\nu\bar{\nu}$

FCNC, loop-induced,
GIM-suppressed in SM
Sensitive to New Physics

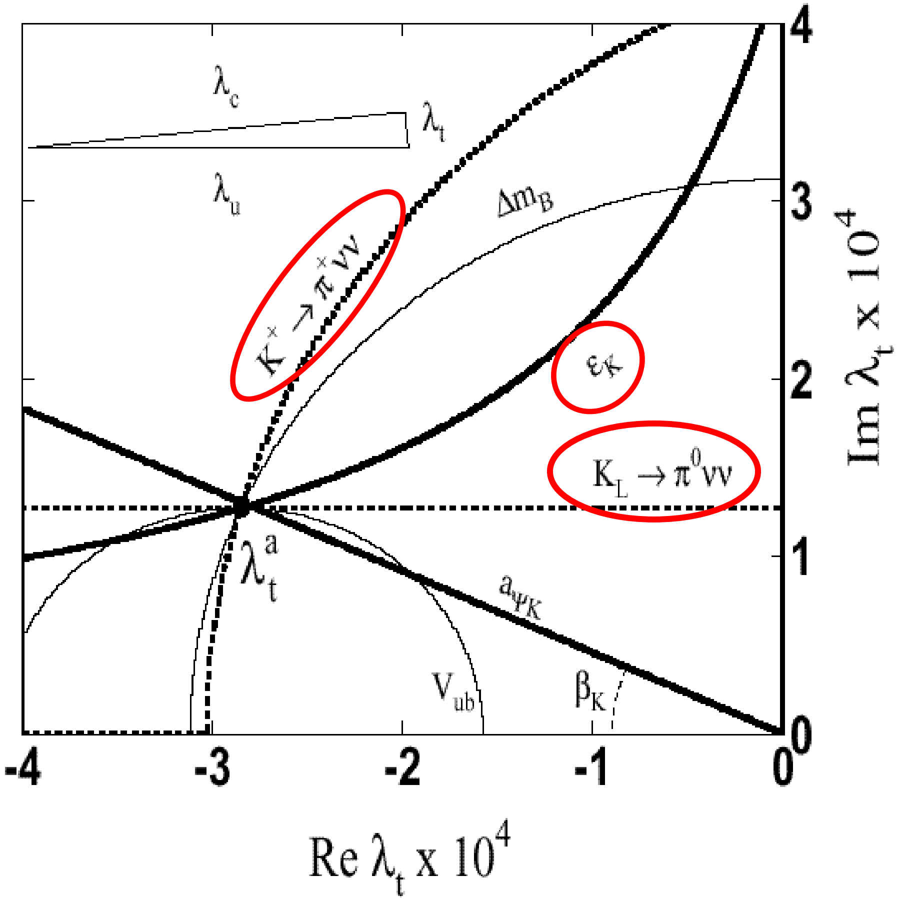
MOREOVER:
No long-range contributions
QCD corrections under control
Single H_{eff} operator with
matrix element linked to K_{e3}



BUT:
BR $\approx 10^{-11}$, unconstrained kinematics, huge backgrounds

Dedicated efforts required!

Kaons and the unitarity triangle



Comparison to B constraints (10% on BR):

- Errors on ρ, V_{td}: better from B
- Errors on η, $\sin 2\beta$: similar to B-factories
- Error on λ_t: always better from K

A. Buras, hep-ph/9905437

The rare decays $K_L \to \pi^0 l^+ l^-$

Three contributions:

1) CP-conserving through $K_L \to \pi^0 \gamma^* \gamma^*$

⇨ estimate from $K_L \to \pi^0 \gamma\gamma$ (KTeV/NA48 disagreement?)

2) Indirect CP-violating through $K_S \to \pi^0 l^+ l^-$

Not suppressed, unlike the $\nu\bar{\nu}$ case:

⇨ measure from $K_S \to \pi^0 l^+ l^-$ (NA48 for e^+e^-)

3) "Direct" CP-violating, short-distance, reliably predicted and interfering with (2): BR=4.3×10^{-12} (e^+e^-), 0.9×10^{-12} ($\mu^+\mu^-$).

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(3) is smaller by $\approx$ 5 for the $\mu^+\mu^-$ case

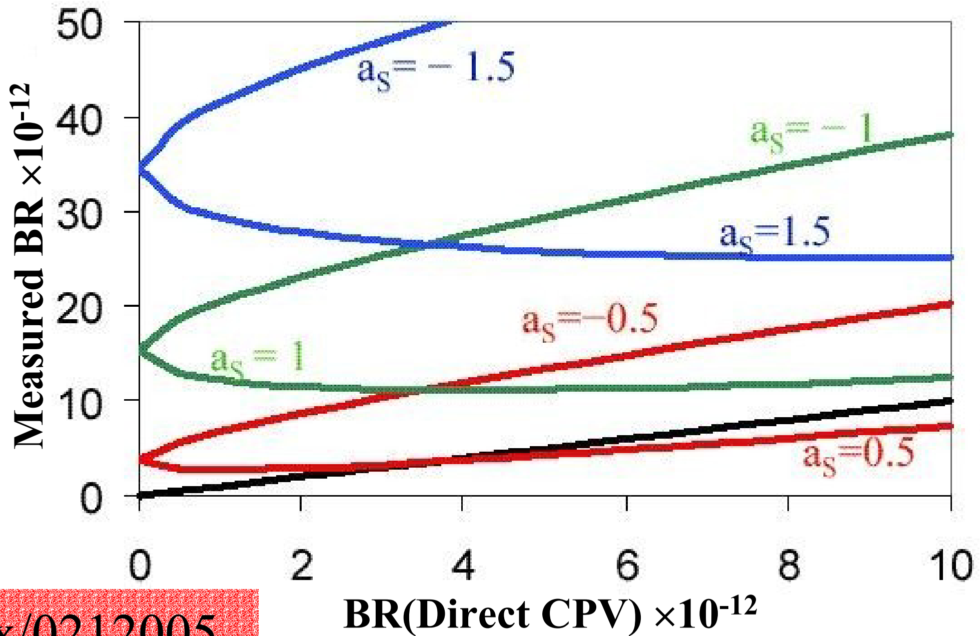
"Greenlee" background $K_L \to \gamma\gamma l^+ l^-$: BR=6×10^{-7} (e^+e^-), 1 $\times10^{-7}$ ($\mu^+\mu^-$)

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

Exp. Limits from KTeV (90% CL):

$BR(K_L \rightarrow \pi^0 e^+ e^-) < 2.8\times10^{-10}$
$BR(K_L \rightarrow \pi^0 \mu^+ \mu^-) < 3.8\times10^{-10}$

Measurement requires accurate background subtraction



L. Littenberg, hep-ex/0212005

$$BR(K_L \rightarrow \pi^0 e^+ e^-)_{CPV} \approx 10^{-12}\left[15.3 a_S^2 - 6.8 a_S \,\mathrm{Im}(\lambda_t)\times10^{-4} + 2.8\,\mathrm{Im}(\lambda_t)^2\times10^{-8}\right]$$

$\lambda_t = V_{ts}^* V_{td}$ $\quad a_S \approx 1$ expected

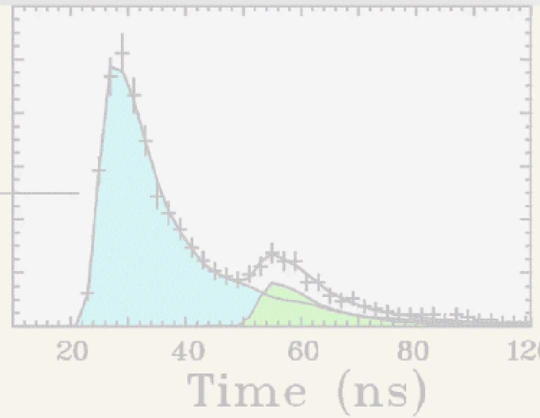
BNL E787: $K^+ \to \pi^+ \nu \bar{\nu}$

BNL E787

Theoretical prediction in the SM:

$BR(K^+ \to \pi^+ \nu\bar{\nu}) = 7.2 \times 10^{-11}$

with small (≈ 7%) uncertainty



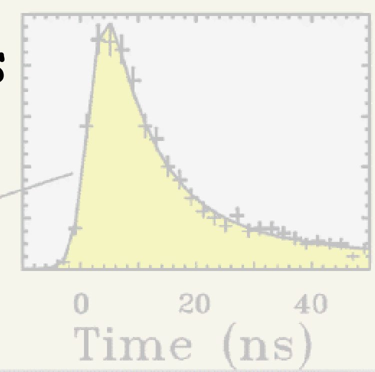
Stopped K, redundant measurements

Detection of $\pi \to \mu \to e$ chain

Momentum region between $\pi\pi$ and $\mu\nu$ peaks

Final result: 2 events (0.15 bkg.)

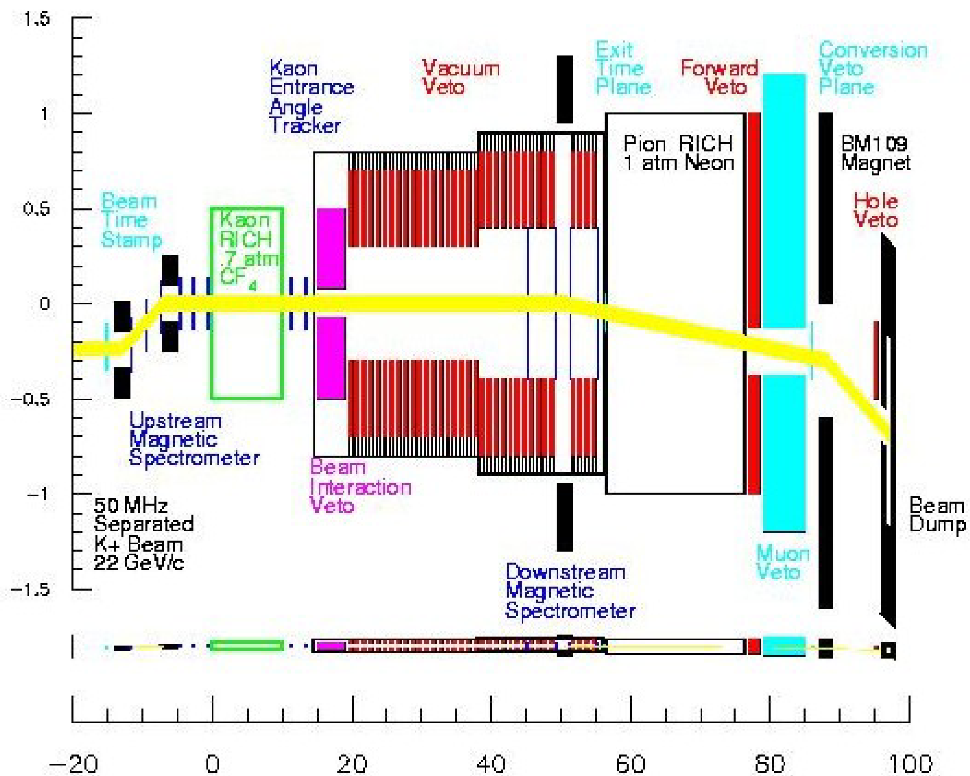
$BR(K^+ \to \pi^+ \nu\bar{\nu}) = 1.56^{+1.75}_{-0.82} \times 10^{-10}$



Improved successor BNL E949 ran in 2002

Future: CKM at FNAL

- In-flight measurement
- RF-separated 22 GeV/c K^+ beam
- Redundant measurements to overconstrain kinematics (spectrometers + RICHs)
- Progress on RF-cavities, photon vetos, straws in vacuum
- Goal: 100 SM events in 2 years ($S/B \approx 10$)
- Data taking in 2007



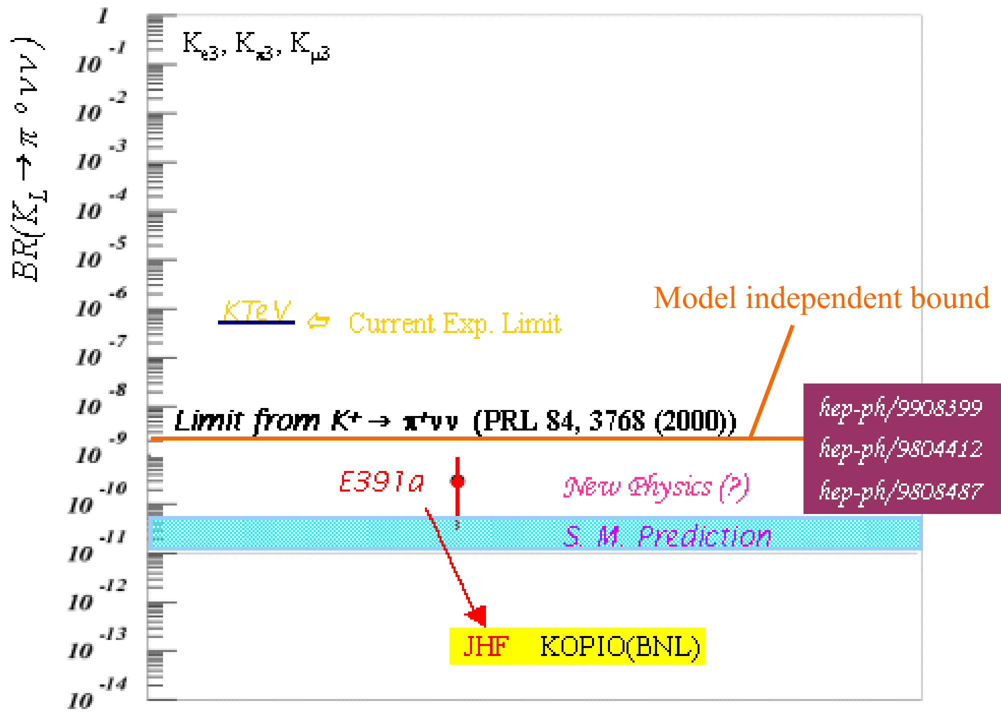
$K_L \to \pi^0 \nu\bar{\nu}$

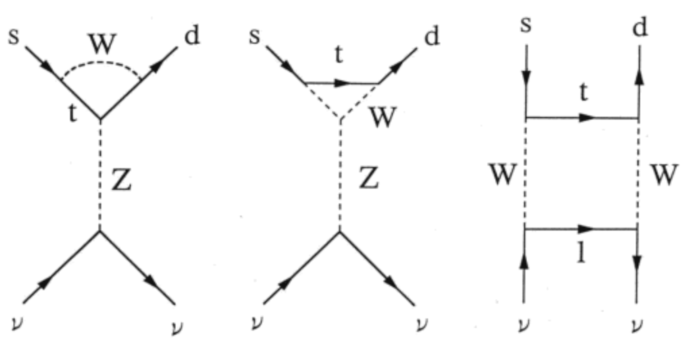
No CP-conserving term
Indirect CP-violating term negligible

Theoretical prediction within the SM:

$$BR(K_L \to \pi^0\nu\bar{\nu}) = 2.7\times10^{-11}$$

With tiny (≈ 2%) uncertainty



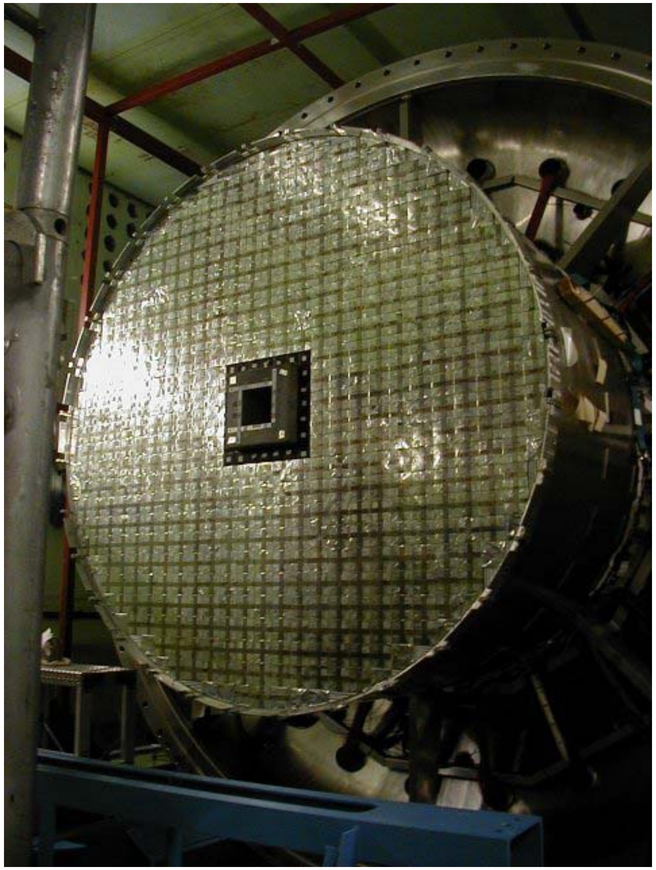


Current KTeV limit:

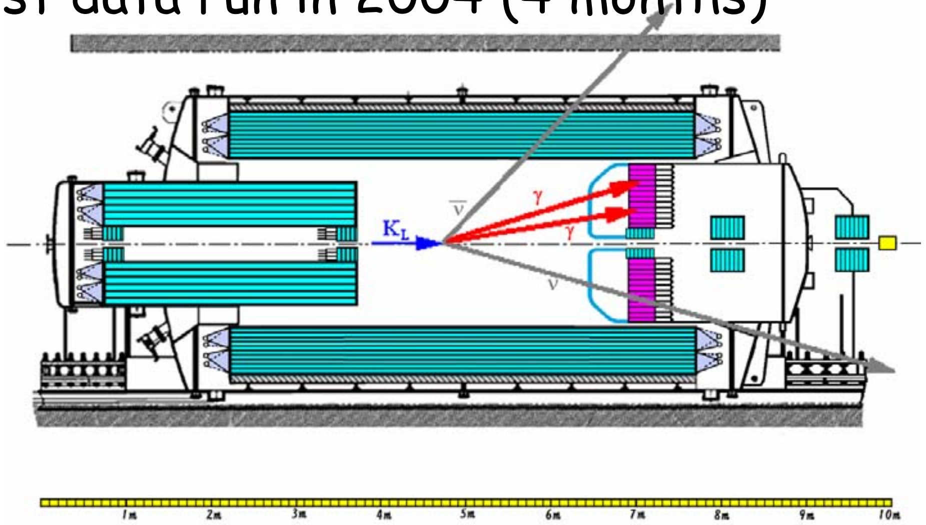
$$BR(K_L \to \pi^0\nu\bar{\nu}) < 5.9\times10^{-7}\ (90\%\ CL)$$

Using $\pi^0 \to \gamma e^+e^-$ decay

KEK E391a: $K_L \to \pi^0 \nu\bar{\nu}$



- Pilot project at KEK-PS
- 2 GeV/*c* "pencil" beam: P_T cut against $\pi^0\pi^0$ to reduce veto requirement to 10^{-4}
- Double decay chamber, 10% acceptance
- "Engineering run" in fall 2002:
- CsI calibration, $K_L \to \pi^0\pi^0$, $\pi^0\pi^0\pi^0$
- First data run in 2004 (4 months)

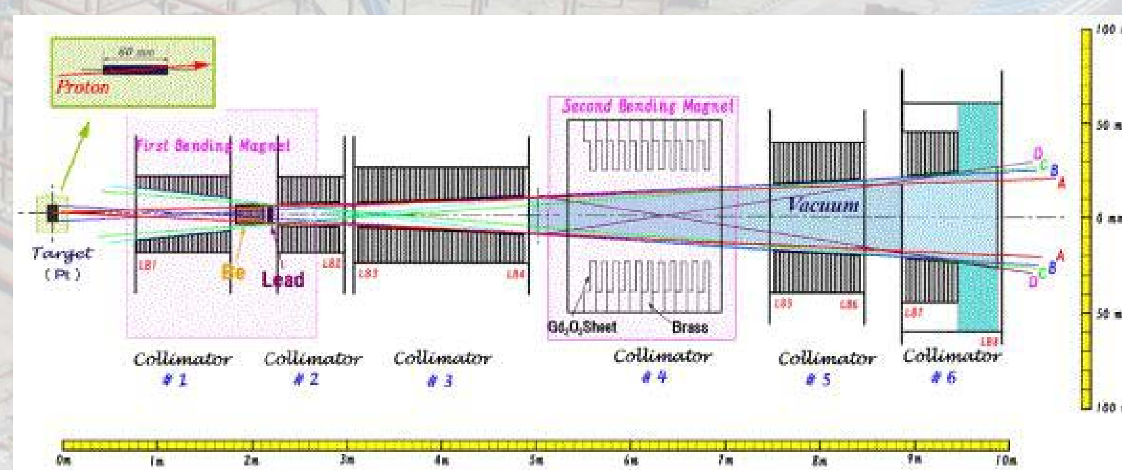


$K_L \to \pi^0 \nu\nu$ at J-PARC

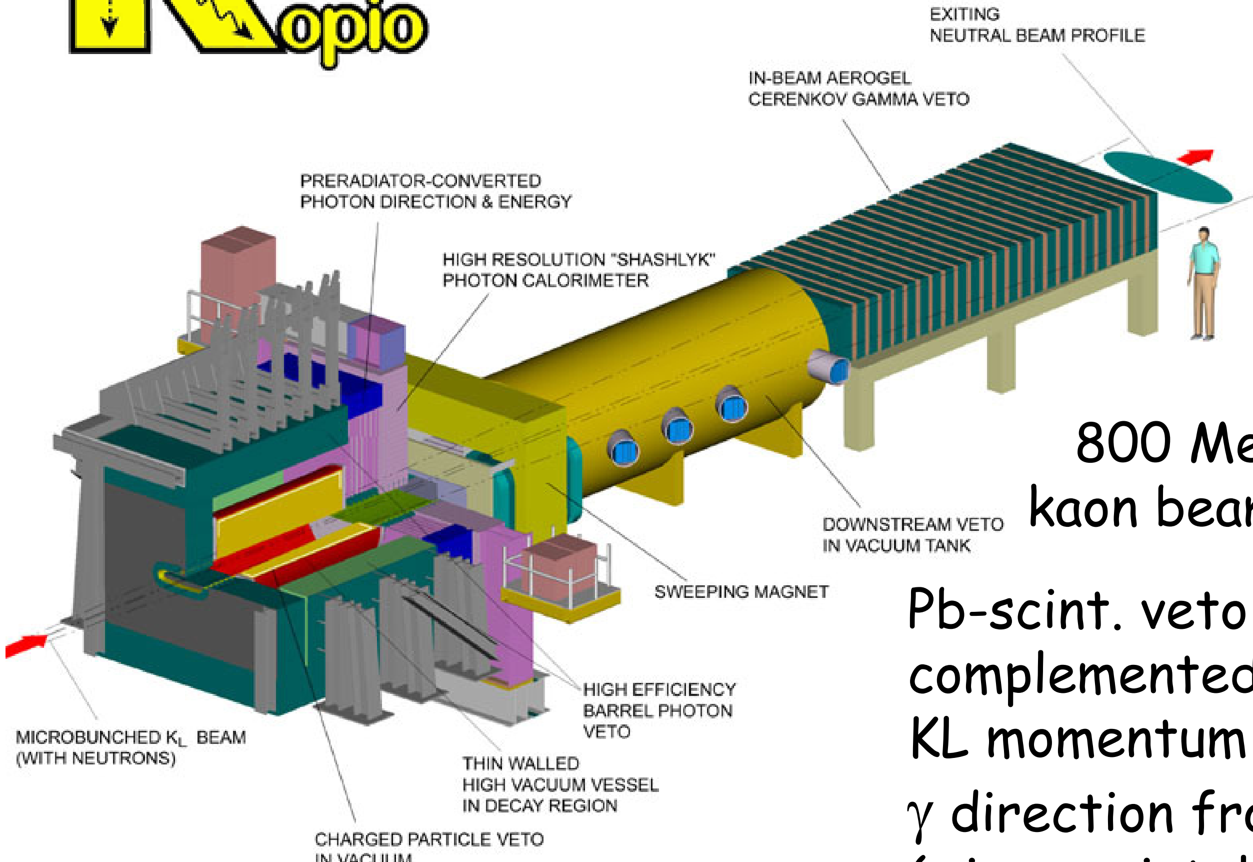
J-PARC schedule: physics start in 2008
50 GeV (30-40 at start) 2×10^{14} p/3.42 s

2 beam lines foreseen in K-hall
2 GeV/c K_L (1.1×10^{9}/pulse)

16% acceptance
Goal: 1000 SM events



KOPIO at BNL : $K_L \to \pi^0 \nu \bar{\nu}$



800 MeV/c microbunched kaon beam

Pb-scint. veto system (10^{-4}) complemented by:

KL momentum from TOF

γ direction from pre-radiator (wires+scint. layers)

"Pancake" beam

KOPIO at BNL

Several feasibility results achieved:

Beam bunching performance proved
(280 ns, goal: 200 ns)

25 mrad resolution with preradiator

Veto efficiency performances

Construction from 2006

Expect 40 SM events (S/B ≈ 2)

How is kaon physics?

CERN: NA48 (K_L) NA48/1 (K_S) analysis, NA48/2 ($K^{\pm}$) running

FNAL: KTeV (K_L) and HyperCP ($K^{\pm}$) analysis, CKM (K^+) in preparation

BNL: E949 (K^+) analysis, KOPIO (K_L) in preparation

KEK: E246 (K^+) analysis, E391a (K_L) ready to run

Frascati: KLOE ($K_{L,S}$, $K^{\pm}$) running, upgrades?

Protvino: OKA ($K^{\pm}$) in preparation

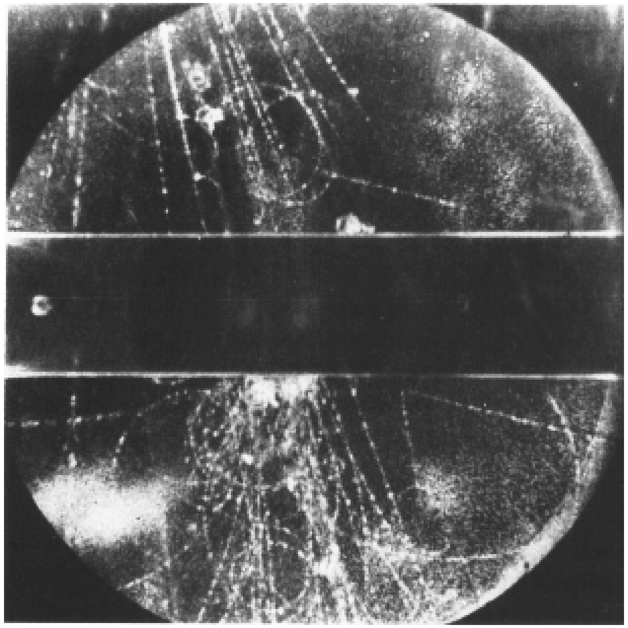
Novosibirsk: VEPP-2000 machine ($K_{L,S}$, $K^{\pm}$) in preparation

J-PARC: Neutral K beam line foreseen

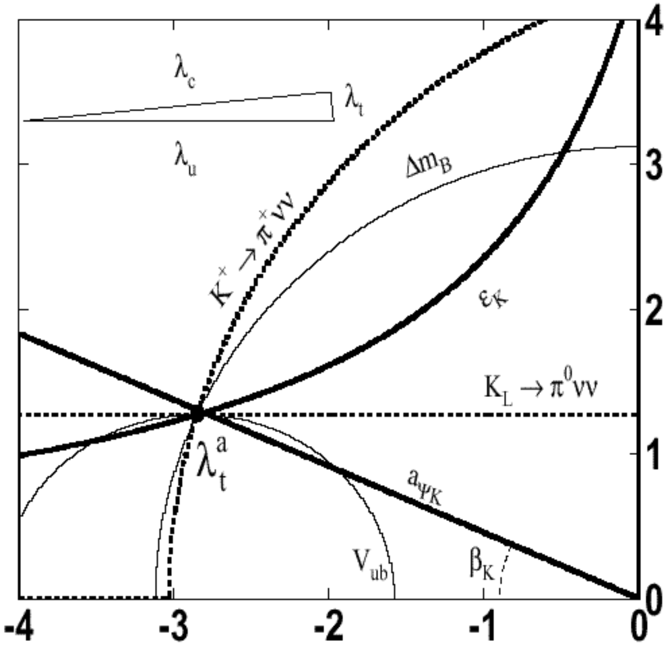
Alive and kicking!

Conclusions?

Once upon a time, kaons delivered many surprises and precious insight…



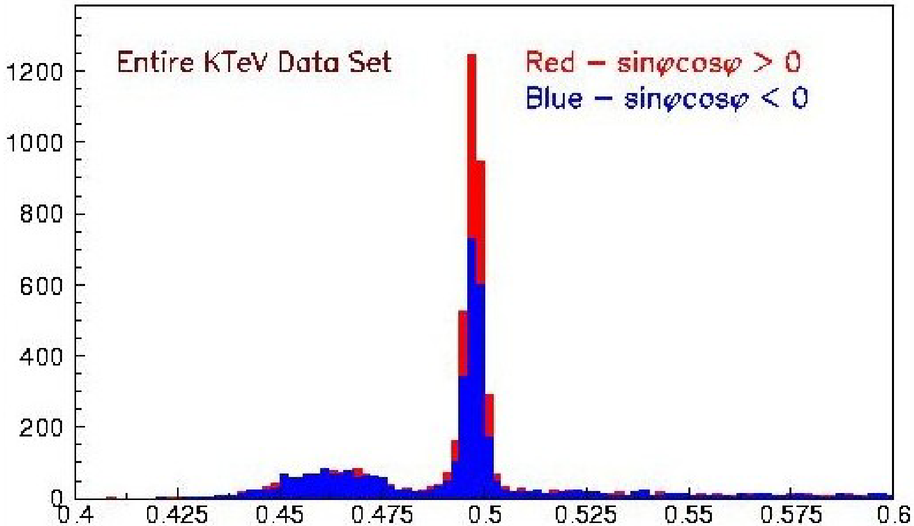
CPV



… they are still doing so today,
and they will in the near future!

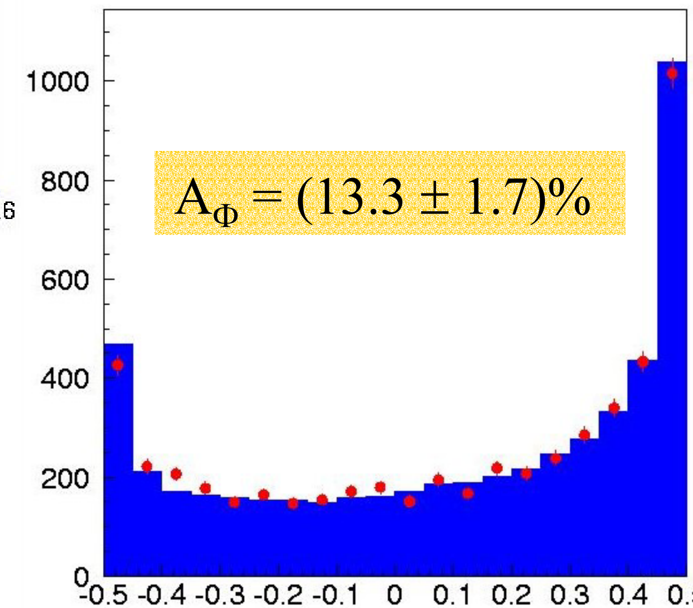
Spare slides

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



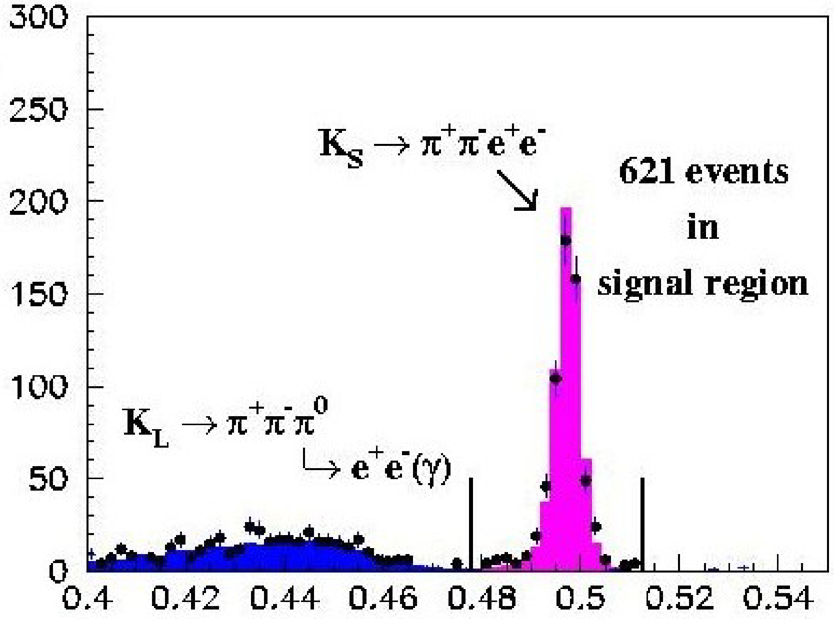
KTeV: K_L

$BR = (3.63 \pm 0.18) \times 10^{-7}$

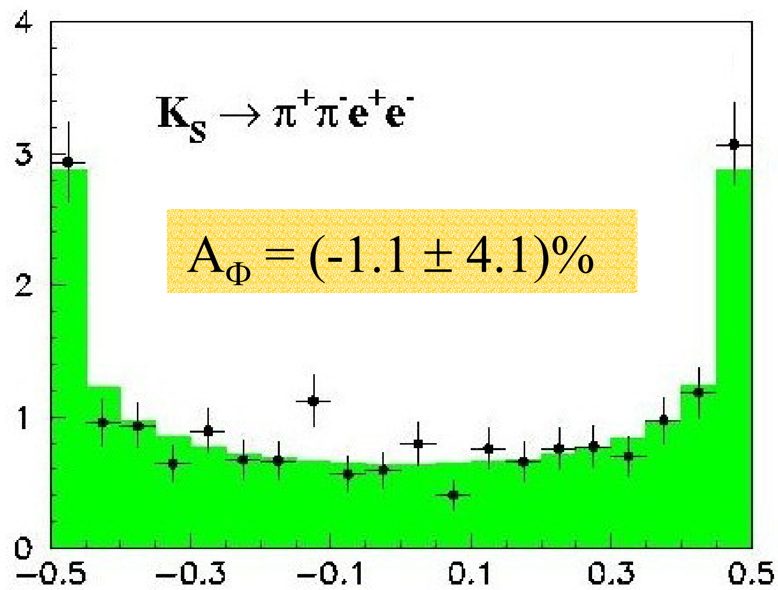


Large CP-violating asymmetry seen

$K_S \to \pi^+\pi^-e^+e^-$



NA48: K_S

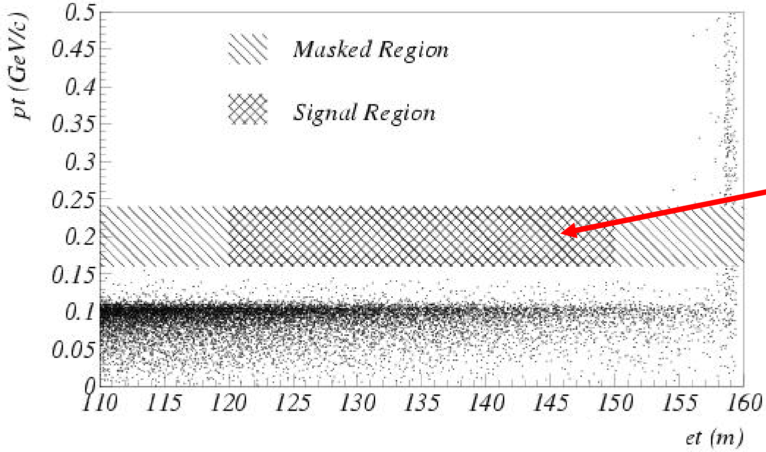


First measurement

$BR = (4.69 \pm 0.30) \times 10^{-5}$

No asymmetry for K_S

KTeV limits on $K_L \to \pi^0 \nu\bar{\nu}$



$BR(K_L \to \pi^0 \nu\nu) < 5.9 \times 10^{-7}$ (90% CL)

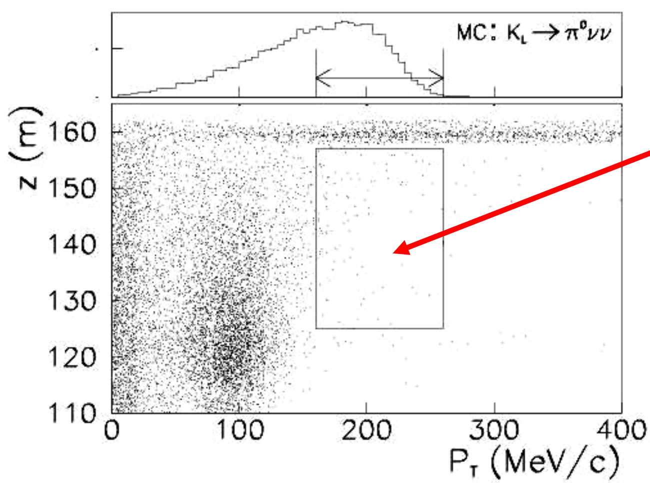
Using $\pi^0 \to \gamma e^+ e^-$ decay

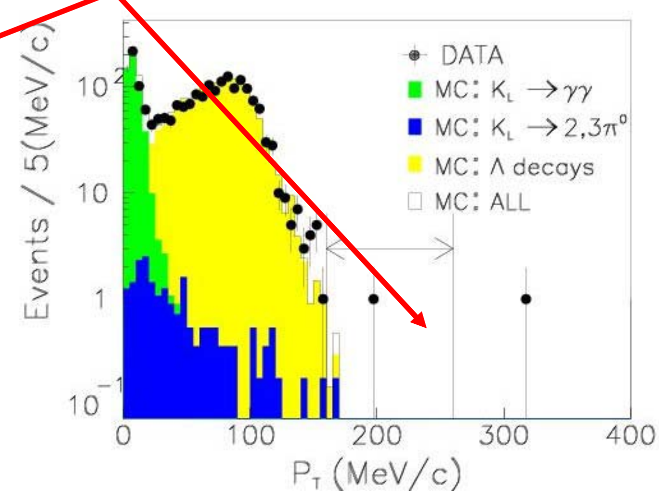
(0.12 events bkg.)

$BR(K_L \to \pi^0 \nu\nu) < 1.6 \times 10^{-6}$ (90% CL)

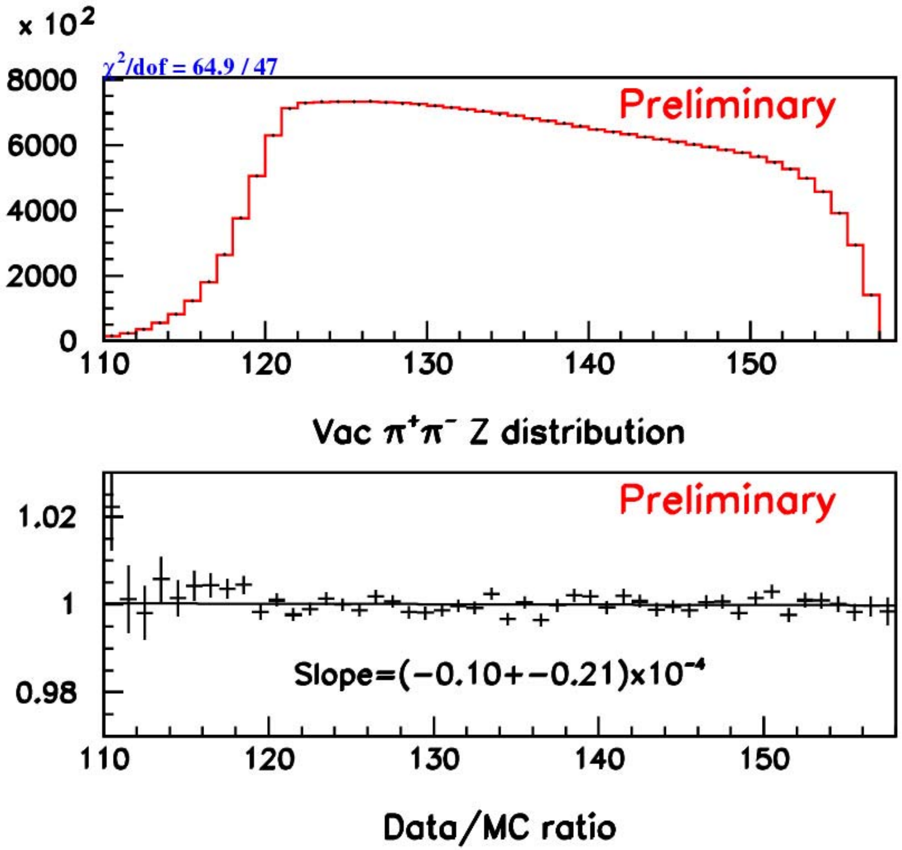
Using $\pi^0 \to \gamma\gamma$ decay

(3.7 events bkg.)





KTeV: ε'/ε improvements



Several improvements in the analysis to reduce systematic errors:

DCH simulation, alignment, reconstruction

Use of angles and improvements for overlapping showers in CsI reconstruction

Stat. Error $\approx 1\times10^{-4}$