Physics with Kaons: Recent and future experiments with charged K

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Outline

- Antefact: Physics with $K^{\pm}$?
- The Stage
- The Plot so far
  - **SM physics: rare $K^{\pm}$ decays, low-energy QCD**
  - **New physics? CP violation, CKM unitarity**
  - **Beyond the SM: T-odd correlations, loop-induced decays**
- Previews of Future Shows
- Conclusions ?

No $K^+ \rightarrow \pi^+ \nu\nu$

Antefact: Physics with $K^{\pm}$?

- Kaons: the "minimal" flavour laboratory
- Long lifetime, "few" decay modes
- Only direct CP violation effects possible
- Difficulties in linking measurements to theory? Not always !
- Form factors, universality
- Several BR poorly known (K^-)
- Good (or even *best*) information on CKM matrix elements
- High sensitivity to BSM physics

K^+ DECAY MODES

K^- modes are charge conjugates of the modes below.

	Mode	Fraction (Γ_i/Γ)	Scale factor/ Confidence level
	Leptonic and semileptonic modes		
Γ_1	$e^+\nu_e$	$(1.55 \pm 0.07) \times 10^{-5}$	
Γ_2	$\mu^+\nu_\mu$	$(63.43 \pm 0.17)\%$	S=1.2
Γ_3	$\pi^0 e^+\nu_e$ Called K^+_{e3}.	$(4.87 \pm 0.06)\%$	S=1.2
Γ_4	$\pi^0\mu^+\nu_\mu$ Called $K^+_{\mu 3}$.	$(3.27 \pm 0.06)\%$	S=1.2
Γ_5	$\pi^0\pi^0 e^+\nu_e$	$(2.1 \pm 0.4) \times 10^{-5}$	
Γ_6	$\pi^+\pi^- e^+\nu_e$	$(4.08 \pm 0.09) \times 10^{-5}$	
Γ_7	$\pi^+\pi^-\mu^+\nu_\mu$	$(1.4 \pm 0.9) \times 10^{-5}$	
Γ_8	$\pi^0\pi^0\pi^0 e^+\nu_e$	$< 3.5 \times 10^{-6}$	CL=90%
	Hadronic modes		
Γ_9	$\pi^+\pi^0$	$(21.13 \pm 0.14)\%$	S=1.1
Γ_{10}	$\pi^+\pi^0\pi^0$	$(1.73 \pm 0.04)\%$	S=1.2
Γ_{11}	$\pi^+\pi^+\pi^-$	$(5.576 \pm 0.031)\%$	S=1.1
	Leptonic and semileptonic modes with photons		
Γ_{12}	$\mu^+\nu_\mu\gamma$	[a,b] $(5.50 \pm 0.28) \times 10^{-3}$	
Γ_{13}	$\pi^0 e^+\nu_e\gamma$	[a,b] $(2.65 \pm 0.20) \times 10^{-4}$	
Γ_{14}	$\pi^0 e^+\nu_e\gamma$(SD)	[c] $< 5.3 \times 10^{-5}$	CL=90%
Γ_{15}	$\pi^0\mu^+\nu_\mu\gamma$	[a,b] $< 6.1 \times 10^{-5}$	CL=90%
Γ_{16}	$\pi^0\pi^0 e^+\nu_e\gamma$	$< 5 \times 10^{-6}$	CL=90%
	Hadronic modes with photons		
Γ_{17}	$\pi^+\pi^0\gamma$	[a,b] $(2.75 \pm 0.15) \times 10^{-4}$	
Γ_{18}	$\pi^+\pi^0\gamma$(DE)	[b,d] $(4.7 \pm 0.9) \times 10^{-6}$	
Γ_{19}	$\pi^+\pi^0\pi^0\gamma$	[a,b] $(7.4\ ^{+5.5}_{-2.9}) \times 10^{-6}$	
Γ_{20}	$\pi^+\pi^+\pi^-\gamma$	[a,b] $(1.04 \pm 0.31) \times 10^{-4}$	
Γ_{21}	$\pi^+\gamma\gamma$	[b] $(1.10 \pm 0.32) \times 10^{-6}$	
Γ_{22}	$\pi^+ 3\gamma$	[b] $< 1.0 \times 10^{-4}$	CL=90%
	Leptonic modes with $\ell\bar{\ell}$ pairs		
Γ_{23}	$e^+\nu_e\nu\overline{\nu}$	$< 6 \times 10^{-5}$	CL=90%
Γ_{24}	$\mu^+\nu_\mu\nu\overline{\nu}$	$< 6.0 \times 10^{-6}$	CL=90%
Γ_{25}	$e^+\nu_e e^+ e^-$	$(2.48 \pm 0.20) \times 10^{-8}$	
Γ_{26}	$\mu^+\nu_\mu e^+ e^-$	$(7.06 \pm 0.31) \times 10^{-8}$	
Γ_{27}	$e^+\nu_e\mu^+\mu^-$	$< 5 \times 10^{-7}$	CL=90%
Γ_{28}	$\mu^+\nu_\mu\mu^+\mu^-$	$< 4.1 \times 10^{-7}$	CL=90%

The Stage

	BR	Physics interest
K_{l2} ($\mu^{\pm}\nu$)	(63.43 ± 0.17) %	$f_{K,}$ universality ($e^{\pm}\nu$)
$K_{\pi 2}$ ($\pi^{\pm}\pi^{0}$) $K_{\pi 3}$ ($\pi^{\pm}\pi^{+}\pi^{-}$) $K_{\pi 3}$ ($\pi^{\pm}\pi^{0}\pi^{0}$)	(21.13 ± 0.14) % (5.58 ± 0.03) % (1.73 ± 0.04) %	ChPT, CP violation
K_{l3} ($\pi^{0}e^{\pm}\nu$) K_{l3} ($\pi^{0}\mu^{\pm}\nu$)	(4.87 ± 0.06) % (3.27 ± 0.06) %	V_{us}, form factors, ChPT, T violation BSM, universality
K_{l4} ($\pi^{+}\pi^{-}e^{\pm}\nu$)	$(4.08 \pm 0.09)\times10^{-5}$	ChPT, ππ interaction
$\pi^{\pm}e^{+}e^{-}$ $\pi^{\pm}\mu^{+}\mu^{-}$	$(2.88 \pm 0.13)\times10^{-7}$ $(7.6 \pm 2.1)\times10^{-8}$	FCNC, ChPT, CP violation
$K_{l2\gamma}$ ($\mu^{\pm}\nu\gamma$) $K_{l3\gamma}$ ($\pi^{0}e^{\pm}\nu\gamma$)	$(5.50 \pm 0.28)\times10^{-3}$ $(2.65 \pm 0.20)\times10^{-4}$	T violation BSM
$K_{\pi 2\gamma}$ ($\pi^{\pm}\pi^{0}\gamma$)	$(2.75 \pm 0.15)\times10^{-4}$	ChPT, CP violation

LFV violation? *Already done*

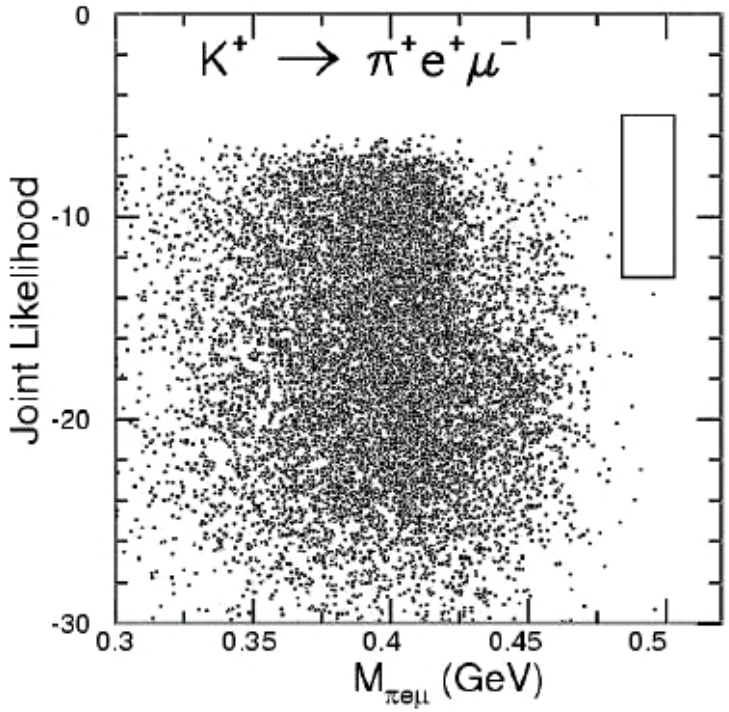
Several dedicated efforts

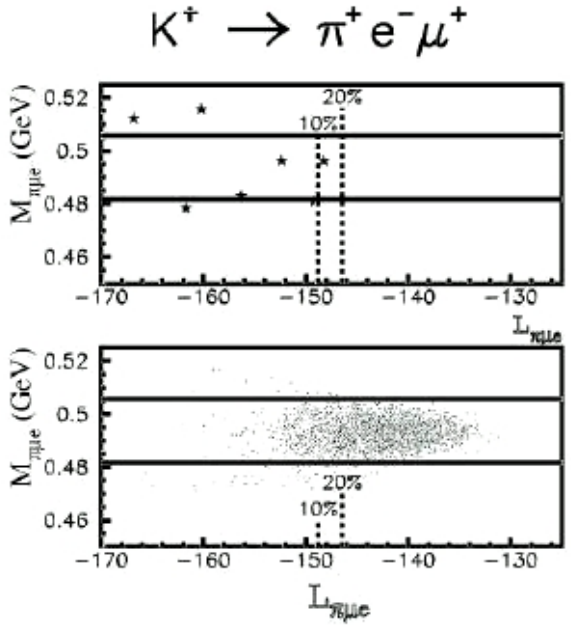
BNL AGS experiments (E865) set very high standards

Flux and backgrounds limiting further progress

Mode	90% BR limit
$K^+ \to \pi^+\mu^+e^-$	2.8×10^{-11}
$K^+ \to \pi^+\mu^-e^+$	5.2×10^{-10}
$K^+ \to \pi^-e^+e^+$	6.4×10^{-10}
$K^+ \to \pi^-\mu^+\mu^+$	3.0×10^{-9}
$K^+ \to \pi^-\mu^+e^+$	5.0×10^{-10}

LFV with K^+





Impressive progress. No new LFV projects with K.
Better background suppression would be required

Hadronic decays: 2π, 3π

$K \to 2\pi, 3\pi$ recomputation at NLO (p^4) in ChPT (Bijnens et al.), with partial inclusion of isospin-breaking effects: rather good agreement of Dalitz plot slopes with expt.

Mode		Expt.	Scale	ChPT fit
$\pi^+\pi^+\pi^-$	g	-0.2154± 0.035	1.4	– 0.216
	h	0.012 ± 0.008	1.4	0.012
	k	-0.0101 ± 0.0034	2.1	– 0.0052
$\pi^\pm\pi^0\pi^0$	g	0.652 ± 0.031	2.7	0.638
	h	0.057 ± 0.018	1.4	0.074
	k	0.0197 ± 0.0054(*)		0.0045

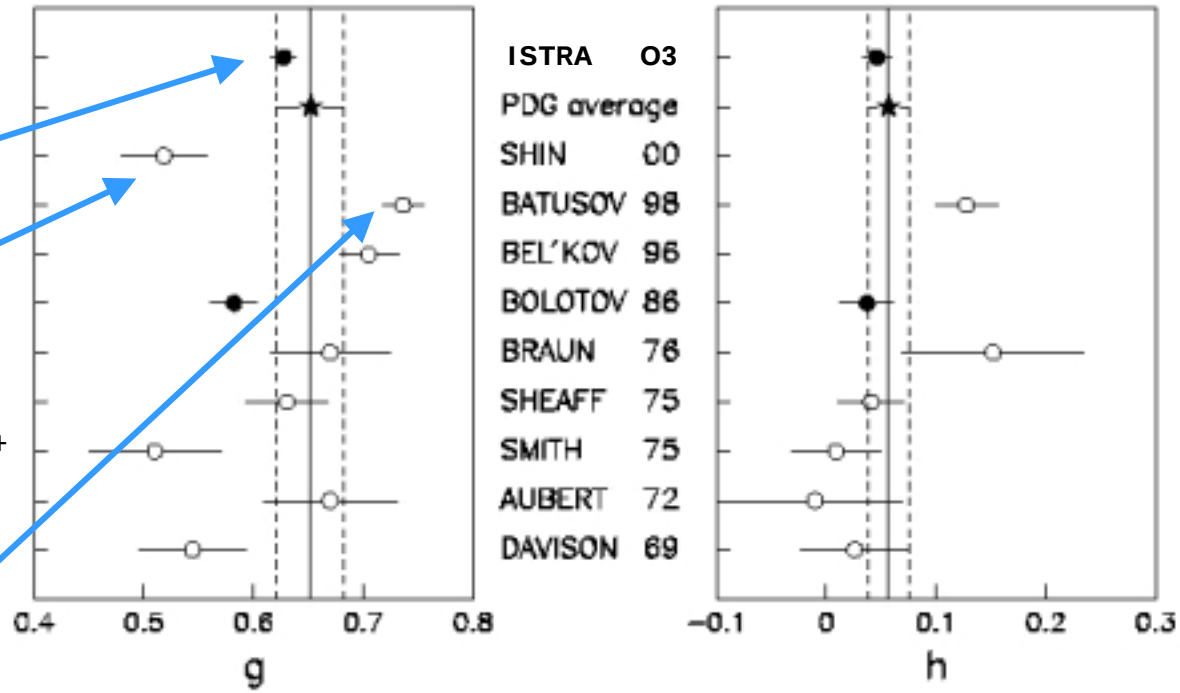
[Side note: fitted value of δ_2-δ_0 = (– 58.2 ± 4)°]

(*) actually improved

Hadronic decays: experiment

Improved $K^{\pm} \to \pi^{\pm}\pi^0\pi^0$ measurements:

- KLOE
  BR at 1% level
- ISTRA+ (Protvino)
  Slopes: 25 GeV/c K^-
  3% K, 252K evts.
- E246 (KEK)
  Slopes (except *h*):
  660 MeV/c stopped K^+
  $\pi/K=7$, 800 evts.
- Disagreement with Serpukhov K^+ results (10 GeV/c, 5% K, 33K evts.)



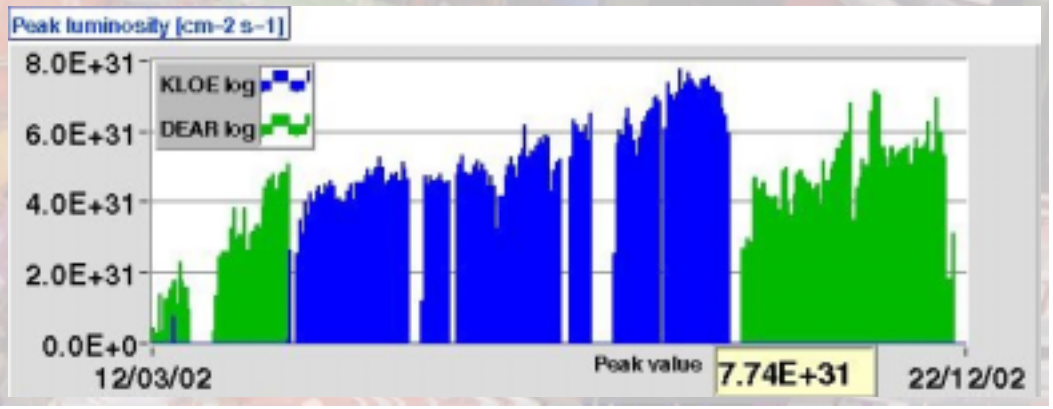
KLOE at DAΦNE

No need to give details on KLOE here…

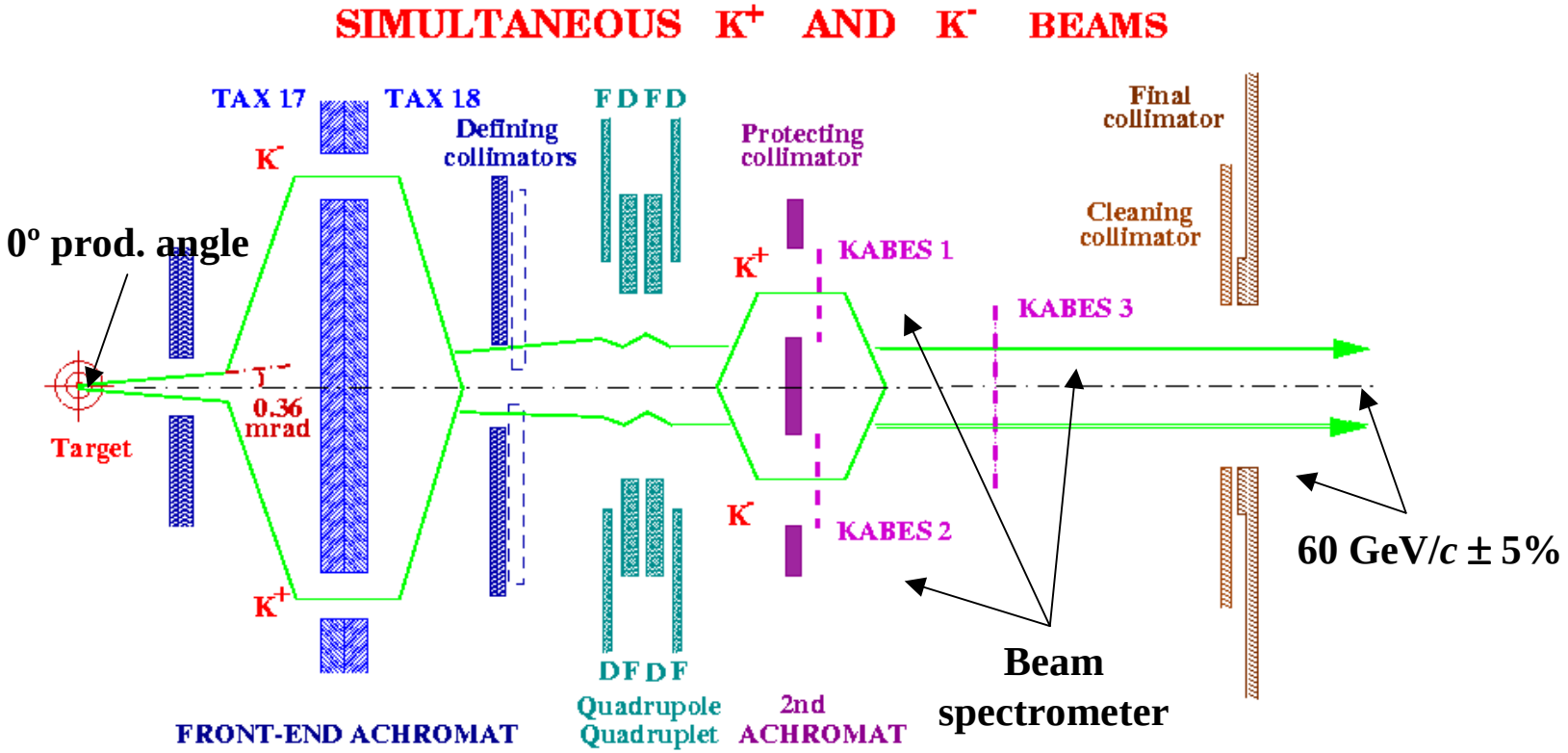
$BR(K^{\pm} \to \pi^{\pm}\pi^0\pi^0) = (1.781 \pm 0.013 \pm 0.016)\ \%$ (440 pb^{-1},<1% bkg)

Good prospects for rare $K^{\pm}$ decays
A strong point: constrained kinematics
High-purity pion ($\pi^{\pm}\pi^0$) and muon ($\mu^{\pm}\nu$) tagging

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

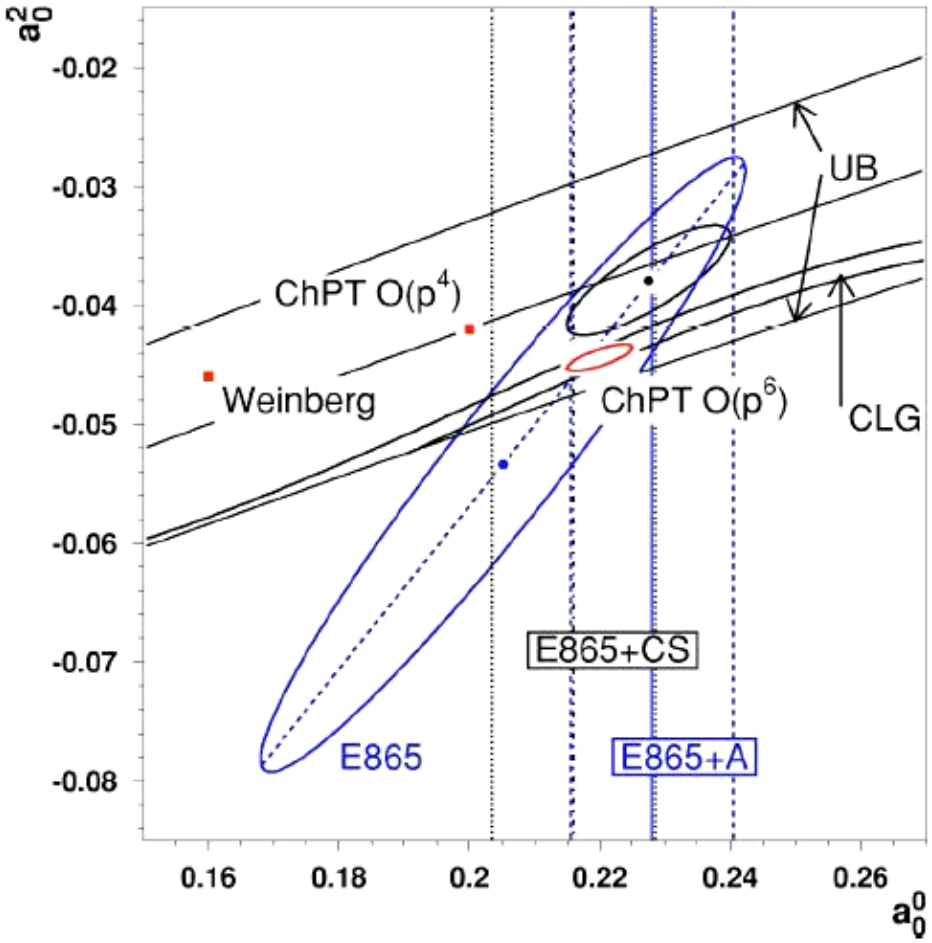


NA48/2 at CERN SPS



New *simultaneous* K+ and K- narrow band beam
Kaon momentum spectrometer

Low-energy ππ physics



- Ke4 decays allow study of low-energy ππ interaction
- Asymmetry between di-pion and di-lepton planes sensitive to phase shifts
- Very high precision two-loop ChPT prediction: $a_0^0 = 0.220 \pm 0.005$
- E865: 400K events $a_0^0 = 0.216 \pm 0.013 \pm 0.003$
- NA48/2 goal: >1M events
- DIRAC goal: $|a_0 - a_2|$ at 6%

CP violation: from ε' onwards

The 30-year long quest for direct CP violation resulted in the first *qualitative* test of the CKM picture of CP violation:

$$\varepsilon'/\varepsilon \neq 0$$

- Superweak model ruled out
- CPV not a peculiarity of neutral kaons

Still however:

- ε'/ε under poor theoretical control (could even be dominated by new physics)
- No effect seen in charged particle decays yet (pure direct CP)

→ **Other CPV measurements needed for *quantitative* checks and searches for other CPV sources (*new physics*)**

CPV: $K^{\pm}$ vs. K^0

- K^0 can exhibit CPV by existence of a decay mode ($\pi\pi$, $\pi^0\nu\nu$), K_L-K_S interference effects, decay distribution asymmetries ($\pi^+\pi^-e^+e^-$).
- Particle antiparticle mixing enriches but complicates phenomenology ($\Delta S=2$)
- $K^{\pm}$ in principle simpler (no mixing, only direct CPV)
- $K^{\pm}$ can exhibit CPV by their comparison (widths, decay distributions): measure both in same detector
- In principle best with initial CP-symmetric state ($p\bar{p}$, e^+e^-)
- No stopped experiments

CP violation in $K^{\pm}$ decays

- $\pi^{\pm}\pi^{+}\pi^{-}$ and $\pi^{\pm}\pi^{0}\pi^{0}$: direct CPV with no $\Delta I=3/2$ suppression as for ε'/ε, *but* small effects in SM (small FSI phases, higher order ChPT)
Asymmetry in linear slopes $O(10^{-5})$, can be $>10^{-4}$ in some regions of SUSY-space. Width asymmetries suppressed.

- $\pi^{\pm}l^{+}l^{-}$: Width asymmetry $O(10^{-5})$ in SM, can be larger in SUSY.
Useful handle from $m_{//}$ dependence.

- $\pi^{\pm}\pi^{0}\gamma$: IB suppressed by $\Delta I=1/2$, DE seen (DE/IB ~ 0.1, M1 type).
New KEK-E470 2003: 4K events (1.2% bkg.)
Interference (E1 DE) not seen.
Width asymmetries $O(10^{-5})$ in SM. γ spectrum asymmetry $O(10^{-4})$

Small SM effects: good probes for new physics

Charge asymmetries

- $A_g(\pi^{\pm}\pi^{+}\pi^{-}) = -0.0070 \pm 0.0053$ (Ford 1972)
- $A_g(\pi^{\pm}\pi^{+}\pi^{-}) = -0.0022 \pm 0.0015 \pm 0.0037$ (HyperCP prelim.)
  1997 data only: 41.8 M K^{+} and 12.4M K^{-} as byproduct
  largest systematics by magnetic fields, secondary beam, MC
- $A_g(\pi^{\pm}\pi^{0}\pi^{0}) = 0.051 \pm 0.028$ (from different experiments)
- Better control of systematics required
- $A_\Gamma(\mu^{\pm}\nu) = 0.0054 \pm 0.0041$
- $A_\Gamma(\pi^{\pm}\pi^{0}) = 0.008 \pm 0.012$
- $A_\Gamma(\pi^{\pm}\pi^{0}\gamma) = 0.009 \pm 0.033$

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})

  Strong point: simultaneous beams allow "double ratio" cancellations. $\Delta g(\tau)$ vs. $\Delta g(\tau')$ comparison.

- **Precise measurement of $\pi\pi$ interaction in K_{e4} decays (>10^6): $\delta(a^0_0) \approx 0.01$**

- **Several rare $K^{\pm}$ decays and CP-violating asymmetries (no absolute K flux measurement)**

- **10^{11} $K^{\pm}$ decays expected in 120d**

2003 run just finished: good performance of the experiment but low SPS efficiency to North Area

Vus

$|V_{us}| = 0.2196 \pm 0.0023$ (PDG2002)
$1-\Sigma_i |V_{ui}|^2 = 0.0032 \pm 0.0014$
(2.2σ violation of unitarity)

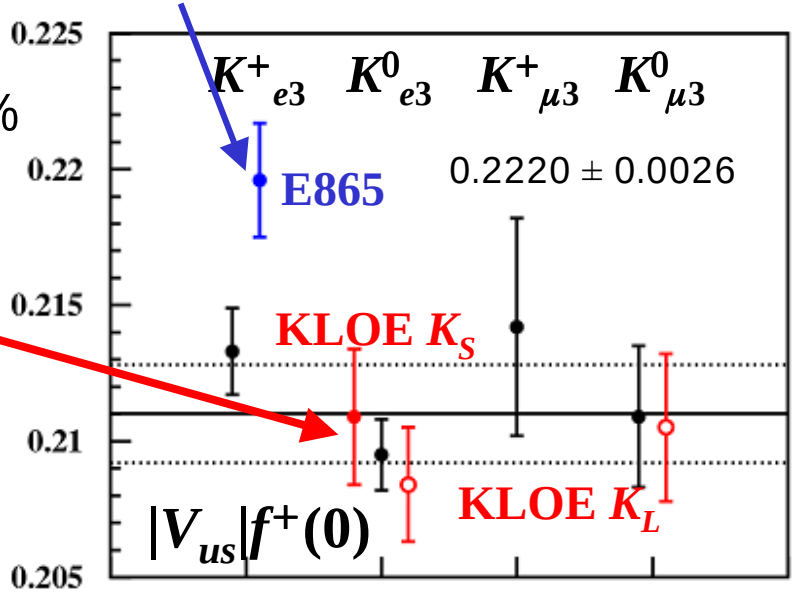
Error: 50% V_{ud} (will reach 10^{-4}) and 50% V_{us} → Measure V_{us} to 10^{-3}

Use K^+_{e3} (single form factor):
BR: 0.9%, τ: 0.1%, $f_+(0)$: 0.8%, λ+: 0.4%

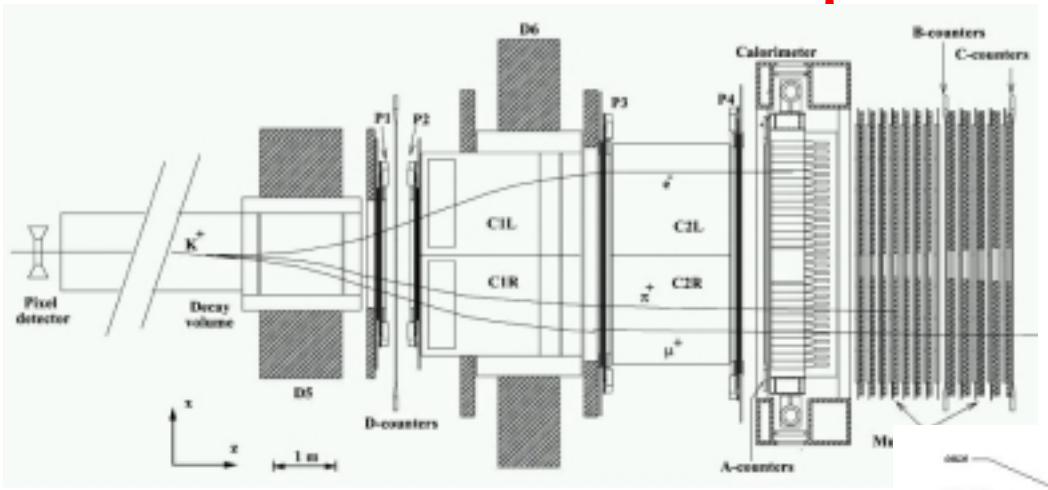
Preliminary KLOE results from 78 pb^{-1} agree with other measurements

Unclear situation:
Wait for KLOE, NA48, KTeV

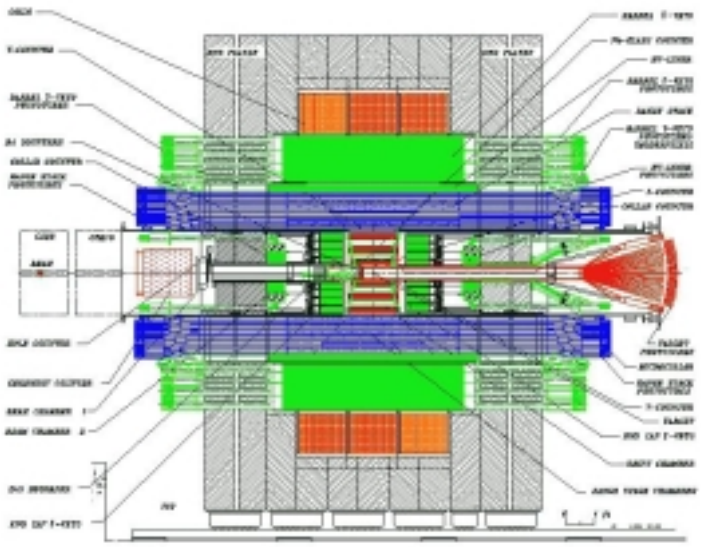
E865 result
1 week low-intensity run, 70K events, partial π^0_D rec., radiative corr., 2.5% bkg:
$(5.13 \pm 0.02 \pm 0.09 \pm 0.04)\%$
agrees with unitarity



BNL experiments



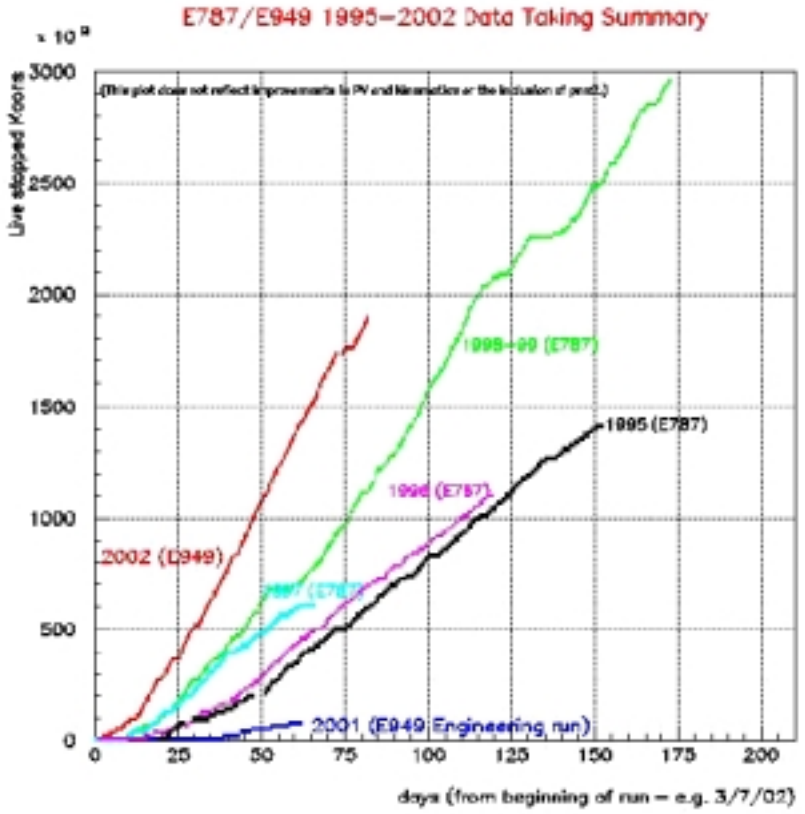
E865: completed
6 GeV/c
Pixel+Cerenkov for K
Spectrometer with dead region, Shashlyk calorimeter



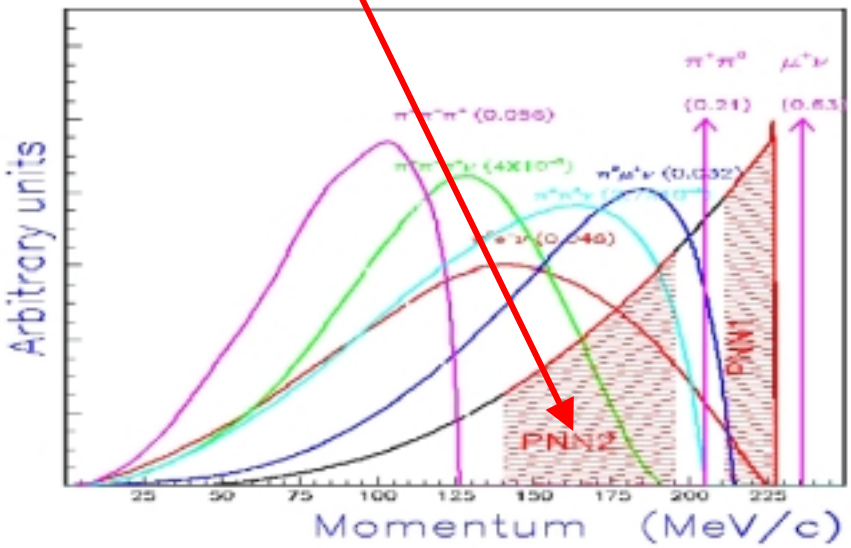
E949 (upgraded E787)
Ran 12 wks in 2002, New run?
Stopped K ($K/\pi>3$), redundant measurements

Detection of $\pi\rightarrow\mu\rightarrow e$ chain
Better vetos, trigger, DAQ, flux x2

E949 data



Investigation of region below $\pi^+\pi^0$ peak, background by pion nuclear interactions



More on semileptonics

No more trace of anomalous S,T couplings:

$$f_S / f_+(0) = -0.002 \pm 0.026 \pm 0.014$$
$$f_T / f_+(0) = -0.01 \pm 0.14 \pm 0.09$$

KEK-E246 $\pi^0 e^+ \nu$ measurement: 40K events

$$f_S / f_+(0) = 0.002^{+0.020}_{-0.022} \pm 0.003$$
$$f_T / f_+(0) = 0.021^{+0.064}_{-0.075} \pm 0.026$$

New ISTRA+ $\pi^0 e^- \nu$ form factor measurements: 550K events

μ/e universality test by KEK E-246: λ_0 extraction from $BR(\pi^0 \mu^+ \nu)/BR(\pi^0 e^+ \nu)$ agrees with direct measurement

T-violation searches

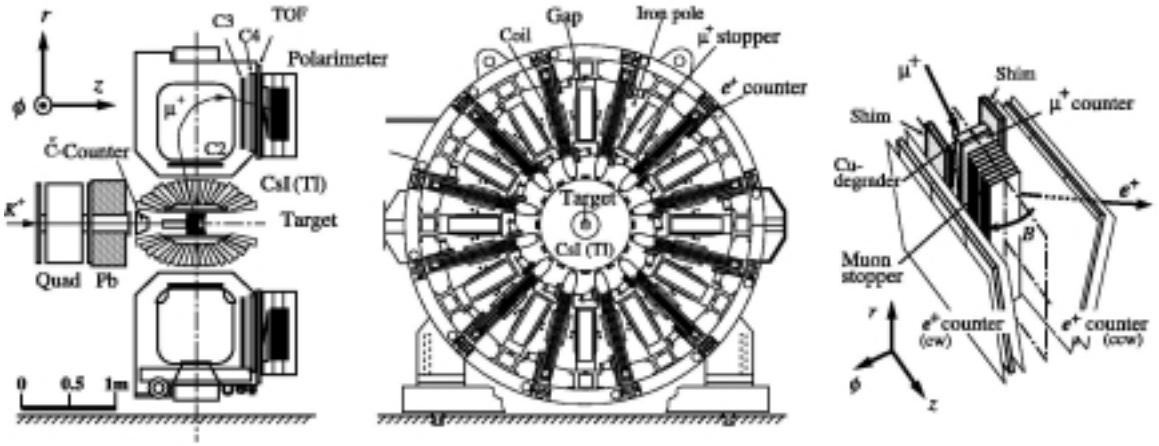
- $P_T(\mu)$ orthogonal to decay plane in 3-body decays (T-odd correlation).

Tiny (EM) FSI in SM: probe of New Physics

Mode	BR	P_T (KEK-E246)	P_T (SM)
$\pi^0\mu^+\nu$	3.3%	$(-1.12 \pm 2.17 \pm 0.90) \times 10^{-3}$	$< 10^{-5}$
$\mu^+\nu\gamma$	0.6%	$(-0.64 \pm 1.85 \pm 0.10) \times 10^{-2}$	$< 10^{-3}$

- Relation between the two discriminates BSM physics
- Stopped K experiments: main systematics from detector misalignment, and magnetic field asymmetry or large in-plane polarization

KEK E246: T-violation



660 MeV/c kaons stopped in absorber

Combined result from 8.3M $\pi^0\mu^+\nu$ decays (1996-2000):

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

Experiment completed: expected final sensitivity

$\delta P_T(\mu) \sim 1.5 \times 10^{-3}$ (0.6×10^{-2} on Im ξ)

Also 10^5 good $\mu^+\nu\gamma$ decays (large backgrounds) in 1996-98

More T-violation

T-odd correlations without polarizations in 4-body decays:

$$\xi = \mathbf{q} \cdot (\mathbf{p_1} \times \mathbf{p_2})$$

Tiny (EM) FSI in SM: probe of New Physics

Mode	BR	A_ξ (SM)	Notes
$\pi^0\mu^+\nu\gamma$	$<6.1\times10^{-5}$	1.1×10^{-4}	S,P,V,A
$\pi^0 e^+\nu\gamma$	2.7×10^{-4}	-0.6×10^{-4}	V,A only

New CPV in S,P couplings: constrained by E246 result

New CPV in V,A couplings: less constrained, can be O(few 10^{-4})

Also: $\pi^+\pi^-\mu^\pm\nu$ (BR = 1.4×10^{-5}), despite large (10^{-1}) FSI, can give independent bounds with O(10^5) events

With both K^+ and K^-: independent from FSI!

Loop-induced decays: $\pi^{\pm} l^{+} l^{-}$

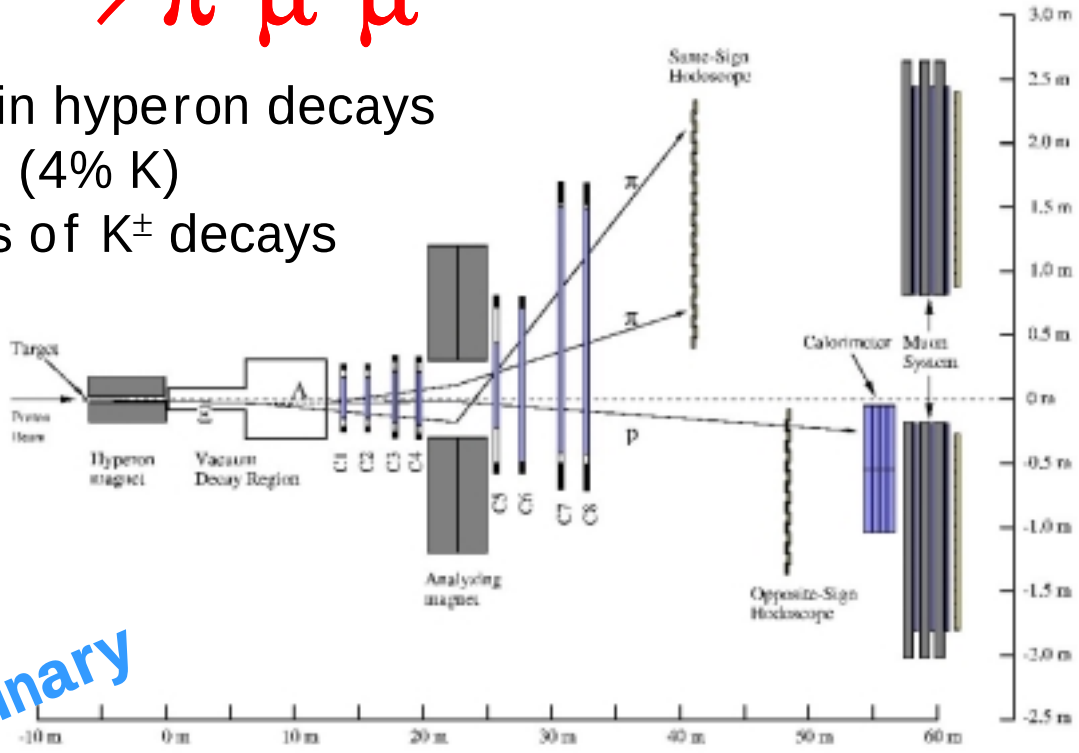
- Long-distance dominated, ChPT prediction
- μ/e ratio: now $\dfrac{BR(K^+ \to \pi^+ \mu^+ \mu^-)}{BR(K^+ \to \pi^+ e^+ e^-)} = 0.28$

  in agreement with SM prediction
- Inconsistency with E787 $\pi^{\pm}\mu^{+}\mu^{-}$ BR result
- $\pi^{+}e^{+}e^{-}$: BR at 0.5%, form factor slope at 10%. E865 10K events, 1.2% bkg.
- $\pi^{+}\mu^{+}\mu^{-}$: BR at 17%. E865 430 events in 6 wks (7% bkg.), stat. limited
- Tiny width asymmetries in SM ($10^{-4} \div 10^{-5}$) could be enhanced in SUSY up to 10^{-3} for $m_{ll} > 2m_{\pi}$

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

Main goal: CP violation in hyperon decays
170 GeV/c secondaries (4% K)
Collected large samples of $K^{\pm}$ decays

Systematics from bkg. subtraction and trigger efficiency



From 1997 statistics (≈1/5): 100 events

Preliminary

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

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

More decays…

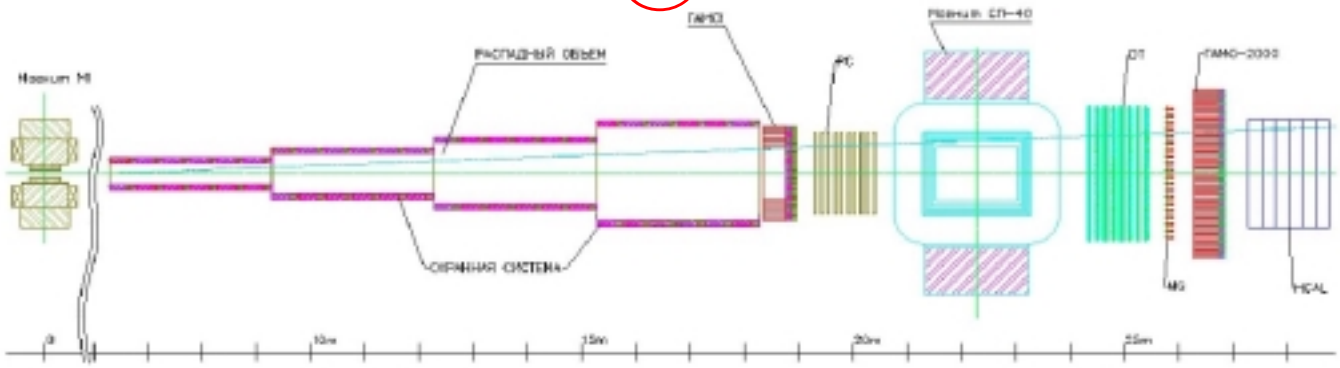
- $\pi^{\pm}\gamma\gamma$: BR = $(1.1 \pm 0.3 \pm 0.1) \times 10^{-6}$: 31 events by E787 (region 2). Free $O(p^4)$ parameter, important $O(p^6)$ contribution (all terms which appear in $K_L \to \pi^0\gamma\gamma$ and $K_S \to \pi^0\gamma\gamma$ appear), tiny width asymmetry $O(10^{-4})$ (up to few 10^{-3} in SUSY).
Photon spectrum can discriminate among models.

- $l^{\pm}\nu l^{+}l^{-}$: $e^{+}\nu e^{+}e^{-}$: BNL-E865 410 evts. $\mu^{+}\nu e^{+}e^{-}$: BNL-E865 2700 events (10-20% background). $l^{\pm}\nu\ \mu^{+}\mu^{-}$ not yet seen (expected at similar BR). Form factors: ChPT test.

- $\pi^{\pm}\gamma$: rather *exotic* search by E787 with 6.7×10^{8} effective Kaons (1.4% acceptance): BR< 3.6×10^{-7}. Statistically limited, more from E949.

- Search for pseudoscalar sgoldstinos (invisible or $\gamma\gamma$)
K^{+} competitive (up to 10^{-4}) for some values of phases:
ISTRA+ $K^{-} \to \pi^{-}\pi^{0}P$ limits at BR < $0.5 \div 2 \times 10^{-5}$

Coming soon:
OKA @ Protvino



New RF-separated beam (CERN-Karlsruhe 1.2MV separators) at U-70 PS in construction: half of beam line ready, 3×10^{13} ppp slow-extracted

15 GeV/c kaons, alternating K+ or K-

Magnetic detector evolved from ISTRA+, GAMS

In preparation, expected run in November 2004

Measurement of 3π Dalitz plot asymmetries @ 1×10^{-4}

T-odd correlations, search for New Physics in K_{l2} decays

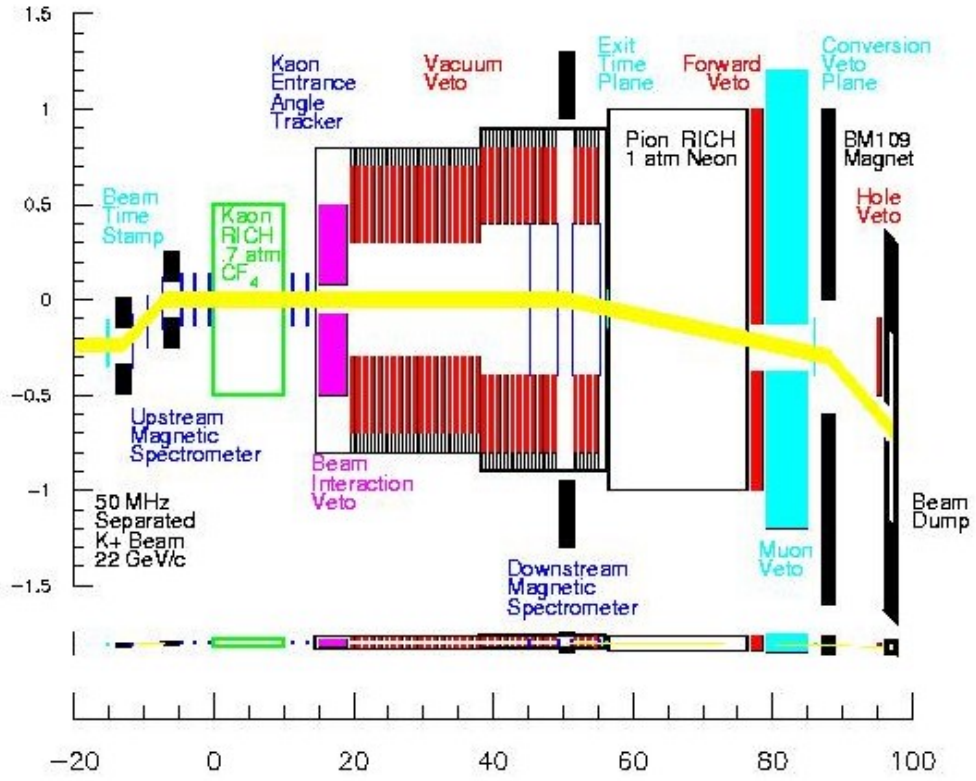
OKA vs. NA48/2 beams

- NA48/2: 10^{12} ppp, 450 GeV/c protons
  $3.8(1.8) \times 10^7$ $K^+(K^-)$/4.8 s spill (duty cycle: 4.8/16.8)
  60 GeV/c, $\Delta p/p \pm 5\%$, 5% K
  Simultaneous K^+/K^-, ran in 2003.
  Aim: 10^{11} $K^{\pm}$

- OKA: 10^{13} ppp, 70 GeV/c protons
  $5(1.6) \times 10^6$ $K^+(K^-)$/2 s spill (duty cycle: 2/9)
  12-18 GeV/c, $\Delta p/p \pm 4\%$, 50% K
  Alternating K^+/K^-, first physics run 2005.
  Aim: 5×10^{11} $K^{\pm}$

Also: 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 $K^+ \to \pi^+\nu\nu$ events, data taking in 2009
Expect more K^+ results...



Coming next: J-PARC

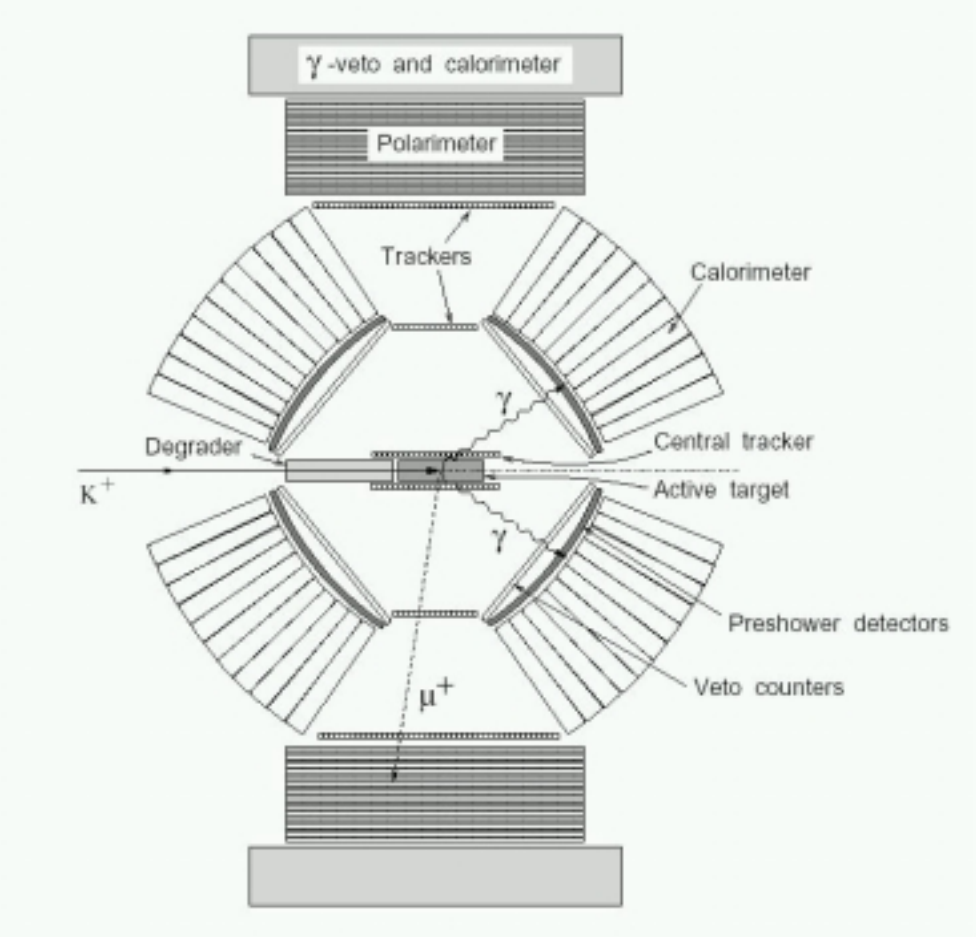
- J-PARC schedule: physics start in 2008
- 50 GeV (30-40 at start) 2×10^{14} p/3.42 s
- 2 beam lines foreseen in K-hall (one might be delayed):
  - 10^7 K^+/s
  - 600-700 MeV/c
  - Double-stage separated (π/K<1)
  - Small (2-3%) momentum bite

Charged kaons at J-PARC

Several LoI received for charged K physics:

- $K^+ \to \pi^+\nu\nu$ experiment
- Upgraded polarization experiment: stopped K^+, active polarimeter, preshower (reduced bkg., systematic x1/10).
  Goal: 1.3×10^{10} $\pi^0\mu^+\nu$ with $\delta P_T(\mu) \sim 1 \times 10^{-4}$.
  Also: 0.7×10^{10} $\mu^+\nu\gamma$ with S/B ~ 8.
- Upgraded E246 (spectrometer for negative particles) running at 1-10% for complete K^+ decay modes measurement
- Ke3 BR measurement at 0.5% using "no-target" E246 at reduced (1/100) intensity
- Pionium and πK atom (lifetime to 6%, $|a_0-a_2|$ to 3%)
- Strange hadron spectroscopy with $K^\pm$ (12 GeV/c, separated)

T-violation experiment at J-PARC



- Improved calorimetry
- Active segmented polarimeter: lower background and better plane definition
- Veto system: background reduction

Charged kaons in the world

BNL-AGS	6 GeV/c or at rest $>10^{12}$ K^+	Unseparated $\pi/K\approx20$ or E×B separated $\pi/K<0.25$	1995+
KEK	At rest $>10^{8}$ K^+	E×B separated $\pi/K\approx6$	1996+
DAΦNE	100 MeV/c 6×10^{8} $K^{\pm}$ so far	ϕ-factory, pure K	2000+
Protvino-U70	25 GeV/c $>10^{9}$ K^-	Unseparated $\pi/K\approx30$	2001+
CERN-SPS	60 GeV/c $<10^{11}$ $K^{\pm}$ so far	Unseparated, $\pi/K\approx10$	2003+
Protvino-U70	12÷18 GeV/c	Separated	2004+
FNAL-MI	22 GeV/c	Separated	2007+
J-PARC	600-700 MeV/c	Separated	2008+

A few years from now: a scenario at LHC start

- All large BR measured with high accuracy
- Universality tests
- Consistent picture of V_{us} from K decays
- $\pi^{\pm}\pi^{+}\pi^{-}$ charge asymmetries to 10^{-4} (and some others to 10^{-3})
- Test of ChPT predictions for 3π, $\pi^{\pm}\pi^{0}\gamma$, $\pi^{\pm}l^{+}l^{-}$, $\pi^{\pm}\gamma\gamma$, $l^{\pm}\nu l^{+}l^{-}$
- *Closer* to the theoretical accuracy in $\pi\pi$ scattering length
-

Physics would like to thank:

CERN: NA48/2 running

FNAL: HyperCP analysis, CKM in preparation

BNL: E949 analysis (run?)

KEK: E246 ongoing analysis

Frascati: KLOE running, upgrades

Protvino: OKA in preparation

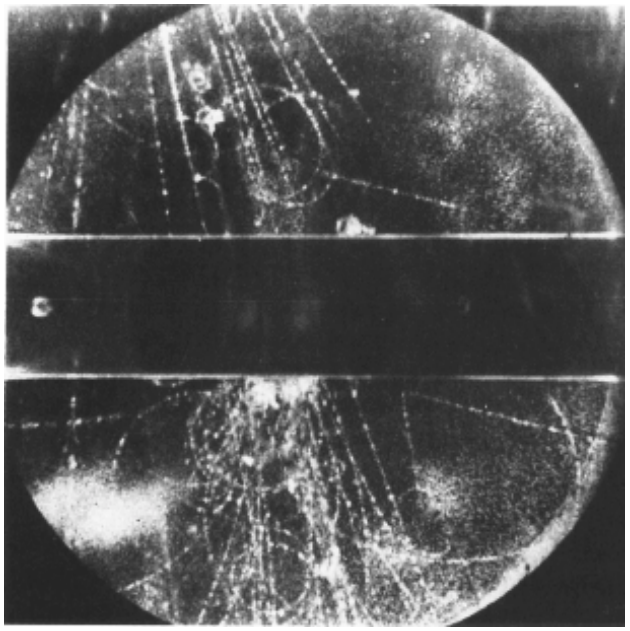
Novosibirsk: VEPP-2000 machine in preparation

J-PARC: K beam line foreseen, several projects

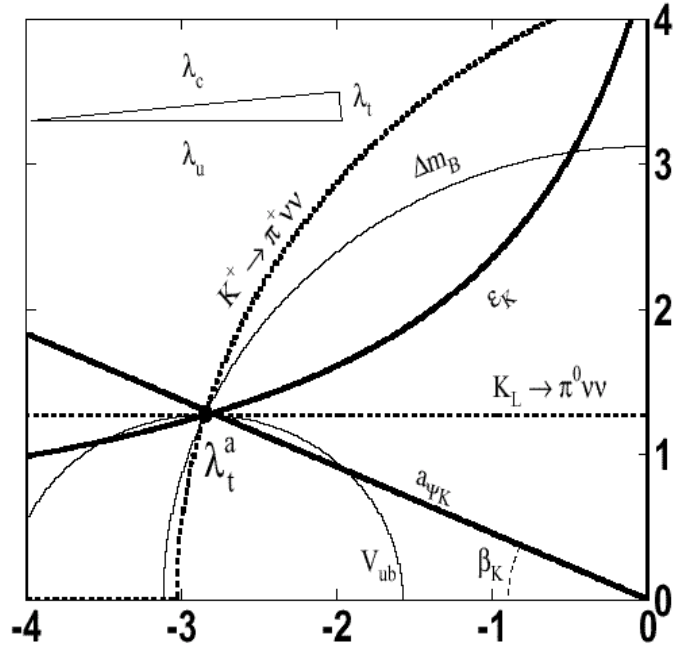
To be continued...

Conclusions?

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



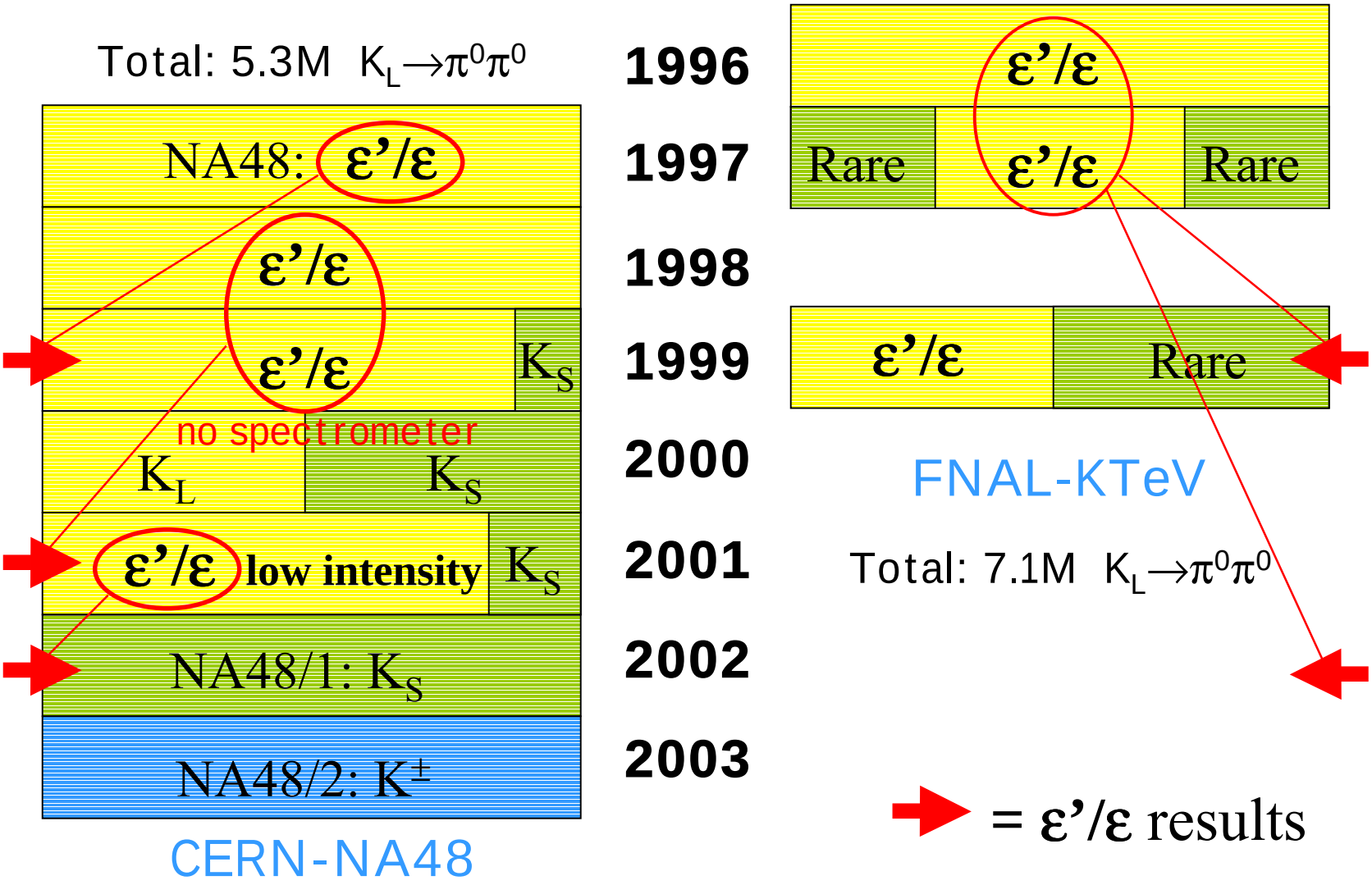
CPV



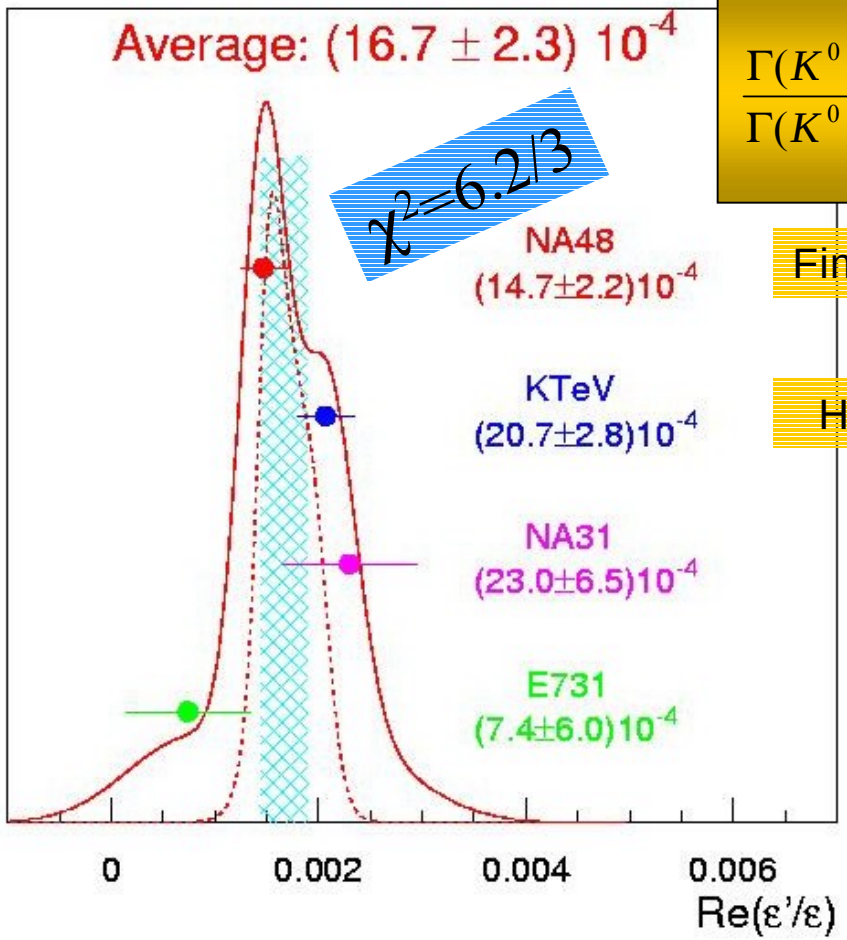
… they are still doing so today, their charged partners can join as well as effective CPV and ChPT probes

Spare slides

NA48 Data Taking Periods



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)

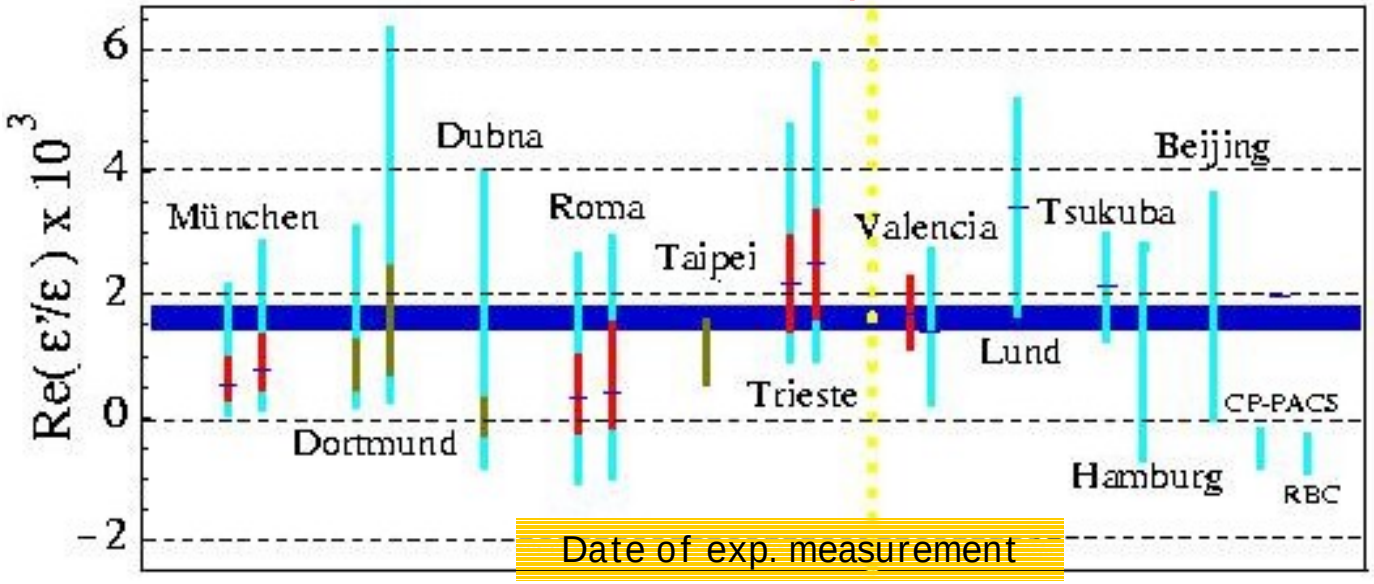
Half statistics (1997)

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

Wait for further results from KTeV and KLOE

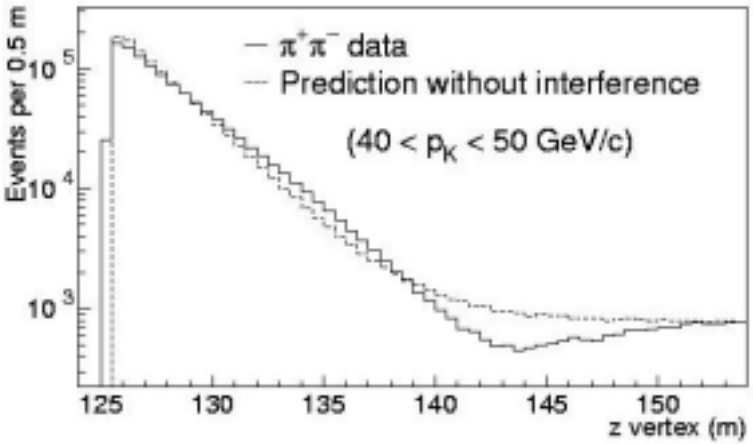
Re(ε'/ε) and the SM

SM theoretical predictions



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

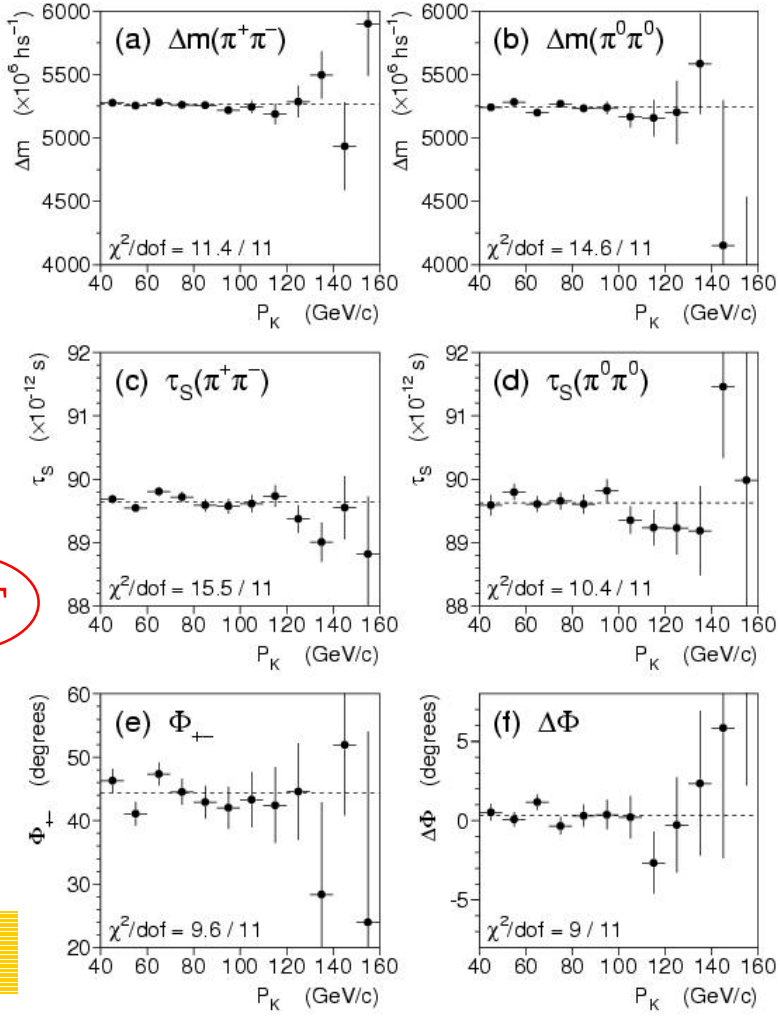
$\phi_{+-} - \phi_{SW} = (0.61 \pm 1.19)^o$

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

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

CPT

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



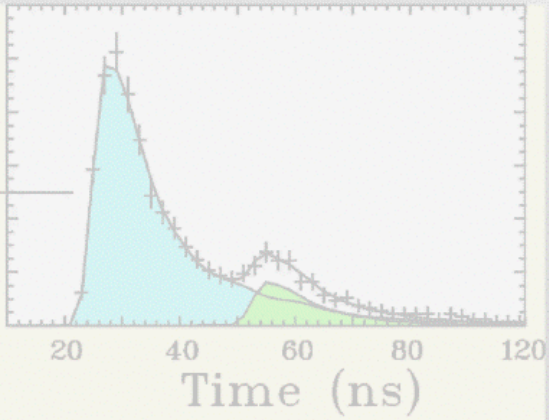
BNL E787: $K^+ \to \pi^+ \nu\bar{\nu}$

BNL E787

Theoretical prediction in the SM:

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

with small (≈ 7%) uncertainty



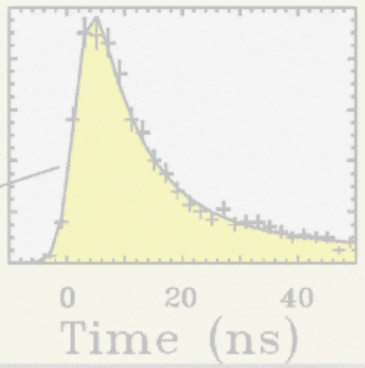
Stopped K, redundant measurements

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