Kaons (30 papers and 63 measurements)

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- Mini-Introduction about myself
- V_{us} and semileptonic kaon decays
- Rare decays and chiral tests
- CP violation

- Graduated in Naples (83), I am a theorist. INFN researcher (86-)
- Harvard (84-86) Georgi $\rightarrow$ chiral lagrangian$\rightarrow$ Finite loops ($K_S \rightarrow \gamma\gamma$)

  Rare Kaon decays/chiral tests ($K_L \rightarrow \pi^0\gamma\gamma$, $K_L \rightarrow \pi^0 e^+ e^-$,..)
- DAΦNE working group (91-) Maiani$\Longrightarrow$ (I and II) $DA\Phi NE\ Handbook$ (Eds. Maiani, Pancheri,Paver)
- my characteristics: study problems only with expt. access
- Other interests: Physics beyond SM, leptogenesis

$K \to \pi l \nu$ and CKM unitarity

$$|V_{ud}|^2 + |V_{us}|^2 + |V_{ub}|^2 = 1 \qquad V_{ub} \text{ negligible}$$

- Superallowed transitions $\Longrightarrow |V_{ud}| = 0.9740 \pm 0.0005 \overset{\text{Unit.}}{\Longrightarrow}$

$$|V_{us}|^{\text{Unit.}} = 0.2265 \pm 0.0022$$

$$|V_{us}|^{\text{PDG04}} = 0.2196 \pm 0.0026$$ Leutwyler,Roos

$$|V_{us}|^{\text{E865}} = 0.2272 \pm 0.0033$$ (for PDG06)

Hyperons : more theoretical work needed Cabibbo *et al*

News expected from pion and nucleon beta decay

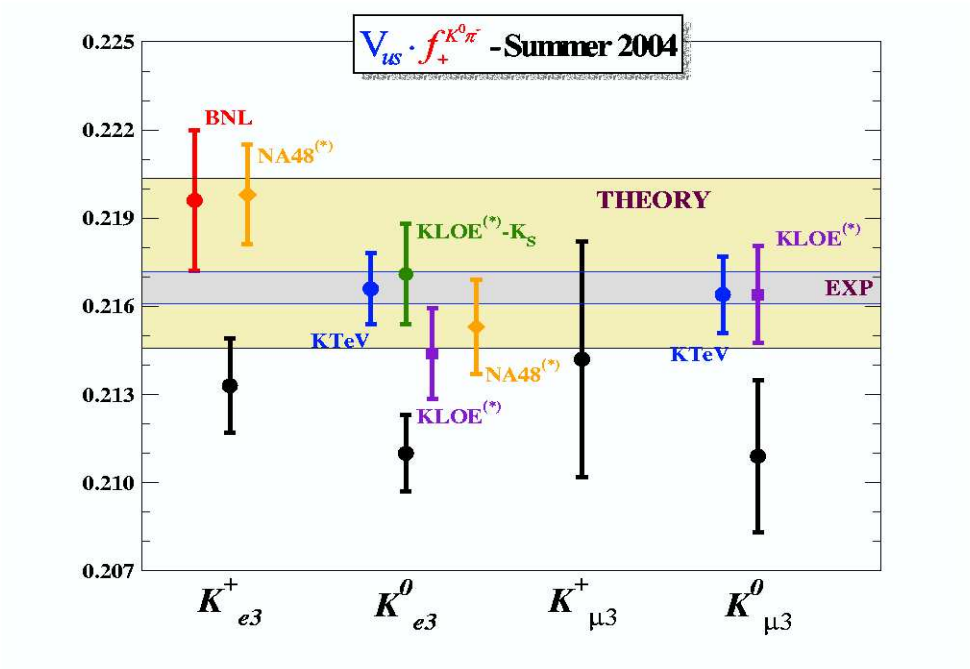
$$\Gamma(K^i_{l3}) = \mathcal{N}_i |V_{us}|^2 |f_+(0)|^2 (1+\delta^l_{rad}) I(\lambda_+, \lambda_0)$$

- $\Gamma(K^i_{l3})$ improvements in: K^+_{e3} (BNL,NA48), $K^0_{e3}, K^0_{\mu 3}$ (KTeV, NA48, KLOE)
- Form factor $f_{+,0}(t) = f_+(0)(1+\lambda_{+,0} t/m_\pi^2)$

  Now measured more accurately. KTeV and ISTRA+ (contrary to NA48) measure non-zero quadr. slope in $f_+(t)$. PDG fits to be redone

  $I(\lambda_+, \lambda_0)$ phase space integral improved by new measurements
- TH radiat./isospin breaking corr. δ^l_{rad} known accurately BUT all expts. must include the same corr.
- $SU(3)_I$-breaking $\longrightarrow$ $f_+(0) = 0.961 \pm 0.008$ Leutwyler Roos,Lattice

THEORY band: $|V_{us}|^{\text{Unit.}} f_+(0)$ $\qquad f_+(0) = 0.961 \pm 0.008$



EXP is the average of all new results
KLOE prel. , NA48 different δ_{rad}

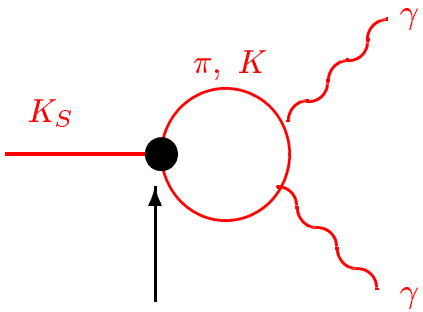
PDG04 are the lower points

INTERPLAY TH and EXP

Isidori,Mescia

Chiral tests

- $K_S \to \gamma\gamma$ Loop contribution finite and unambigous χPT prediction



$\mathrm{Br}_{\chi\mathrm{PT}}(K_S \to \gamma\gamma)$=2.1·$10^{-6}$

(G.D. and Espriu 86, Goity 87)

$(2.78 \pm 0.072) \cdot 10^{-6}$ (NA48 '02)

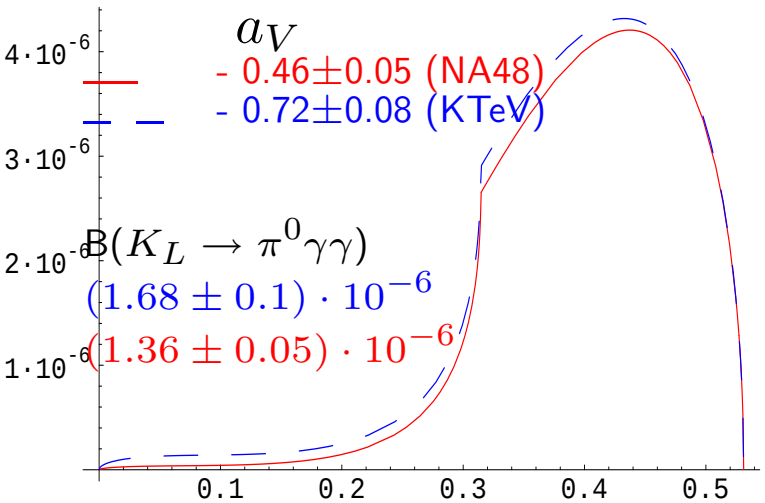
G_8 from $K_S \to \pi\pi$

- NA48 $B(K_S \to \pi^0\gamma\gamma) = (4.9 \pm 1.8) \cdot 10^{-8}$

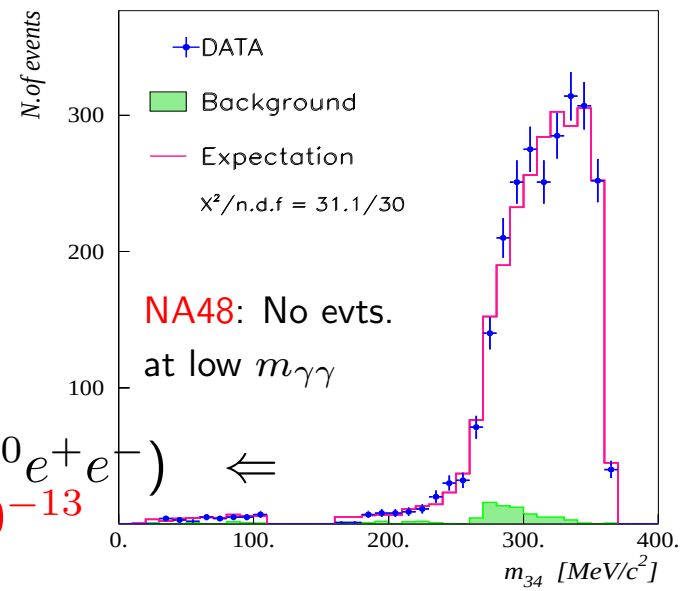
- $\pi\pi$ scattering lengths measured accurately $a_0^0 = 0.216 \pm 0.013$ (K_{l4}) E865

$K_L \to \pi^0\gamma\gamma$

- Diphoton distribution determines the to $K_L \to \pi^0 e^+e^-|_{\text{CP conserving}}$
- Amplitude approximately determined by 1 parameter (a_V); generally 3
- KTeV and NA48: fit with a_V



$B(K_L \to \pi^0 e^+e^-) \Leftarrow$
$< 5 \cdot 10^{-13}$



$K_S \to \pi^0 e^+ e^-$ at NA48/1 Collaboration at CERN PDG04

- 7 events observed (with 0.15 expected background events)

$$B(K_S \to \pi^0 e^+ e^-)_{m_{ee}>165\ \mathrm{MeV}} = \left(3.0^{+1.5}_{-1.2} \pm 0.2\right) \times 10^{-9}$$

$$|a_S| = 1.08^{+0.26}_{-0.21}$$

Using Vector matrix element and form factor equal to 1

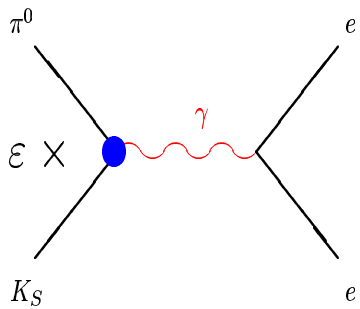
$$B(K_S \to \pi^0 e^+ e^-) = \left(5.8^{+2.9}_{-2.4}\right) \times 10^{-9}$$

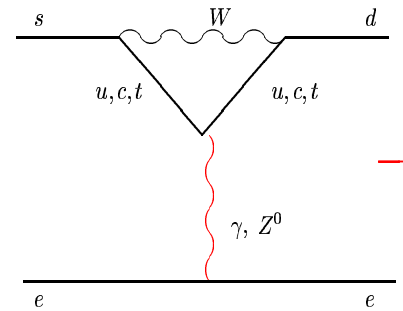
6 events observed in $K_S \to \pi^0 \mu^+ \mu^-$, $Br = \left(2.9^{+1.5}_{-1.2}\right) \times 10^{-9}$ (PDG06)

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

$\mathrm{Br}(K_L \to \pi^0 e^+ e^-) \leq 2.8 \cdot 10^{-10}$ KTeV PDG06

$B(K_L \to \pi^0 \mu^+ \mu^-) <? \cdot 10^{-10}$ KTeV

2) 

$+$ 3) 

$\longrightarrow$ Im λ_t

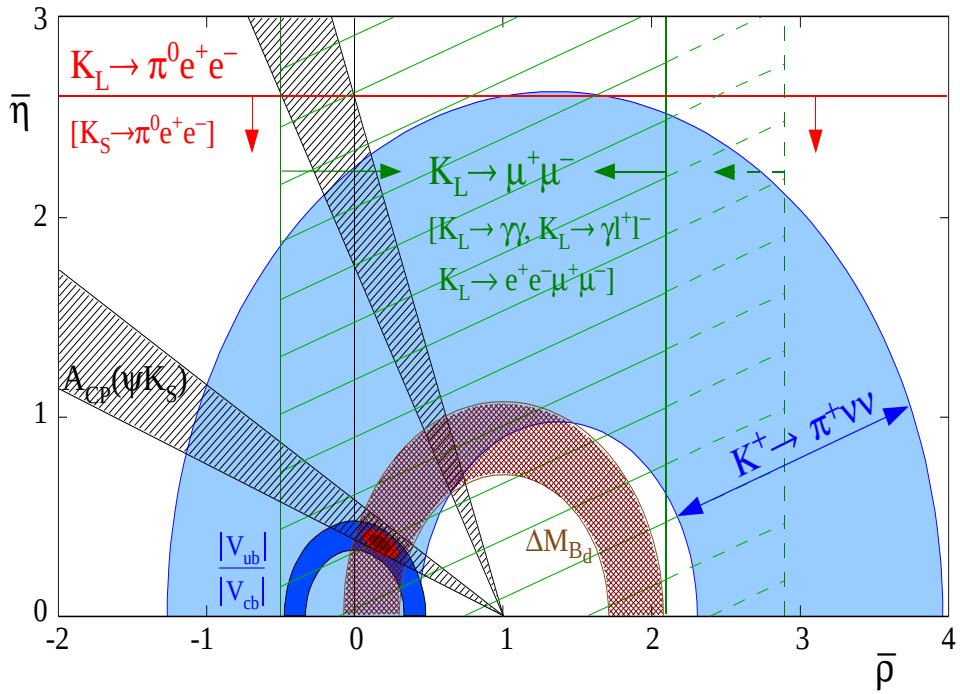
$\lambda_t = V_{td} V_{ts}^*$

$\uparrow$ $\mathrm{B}(K_S \to \pi^0 e^+ e^-) = 4.6 a_S^2 \times 10^{-9}$

Possible large interference: $a_S < -0.5$ or $a_S > 1$; short distance probe even for a_S large.

$$[17.2 \pm \quad 9.4 + \quad 4.7] \cdot 10^{-12}$$

Short distance probe from $K \to \pi\nu\bar{\nu}$



$B(K^+ \to \pi^+\nu\bar{\nu})$
$1.6^{+1.8}_{-0.8}$ E787 (PDG04)
$1.4^{+1.30}_{-0.89}$ E949 for PDG06

$K_L \to \mu^+\mu^-$
KTeV for PDG04: slopes
$K_L \to \mu^+\mu^-\gamma, \mu^+\mu^-e^+e^-$

Isidori,Unterdorfer

News expected from E391a in $K_L \to \pi^0\nu\bar{\nu}$

$K \to 3\pi$ and charge asymmetries

NA48/2 will measure the slope (C,CP) asymmetry in $K^+ \to 3\pi$

$$\frac{\Delta g}{2g} = \frac{g_+ - g_-}{g_+ + g_-} \quad \overset{\text{NA48}}{<} 10^{-4} \quad \overset{\text{SM}}{<} 10^{-5} \quad \overset{\text{PDG}}{<} 7 \cdot 10^{-3} \quad \overset{\text{NP}}{<} 10^{-4}$$

and the charge asymmetry in $K^+ \to \pi^+\pi^0\gamma$ ($E1$ and $M1$ will be measured)

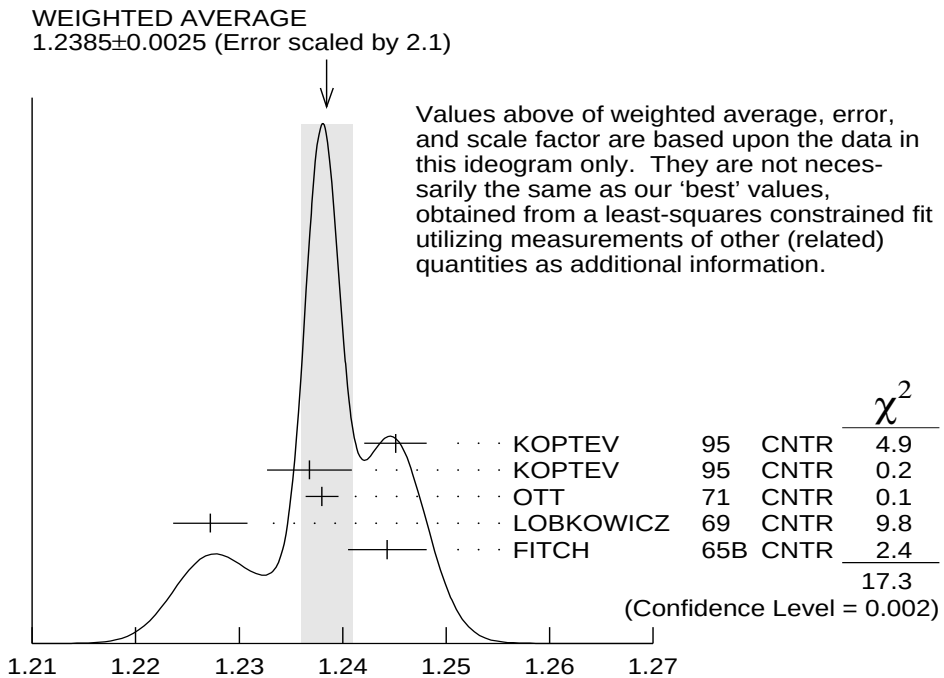
Istra+ has measured linear and quadratic slopes in $K^+ \to \pi^+\pi^0\pi^0$ for PDG04

HyperCP has measured the CP asymmetry in $K^+ \to \pi^+\mu^+\mu^-$ $-0.02 \pm 0.11 \pm 0.04$ PDG04

NA48 and KLOE will accurately measure $Br(K_L \to \pi^0\pi^0\pi^0)$

KLOE will measure $Br(K_S \to \pi^+\pi^-\pi^0)$ (Bell-Steinberger relation improved)

KLOE measurement of K^+ lifetime



τ_{K^+} measured:

in flight (left bump)

or at rest (the other 4 data points)

PDG

KLOE will measure K^+ lifetime in flight

K_L CP Violation Fit

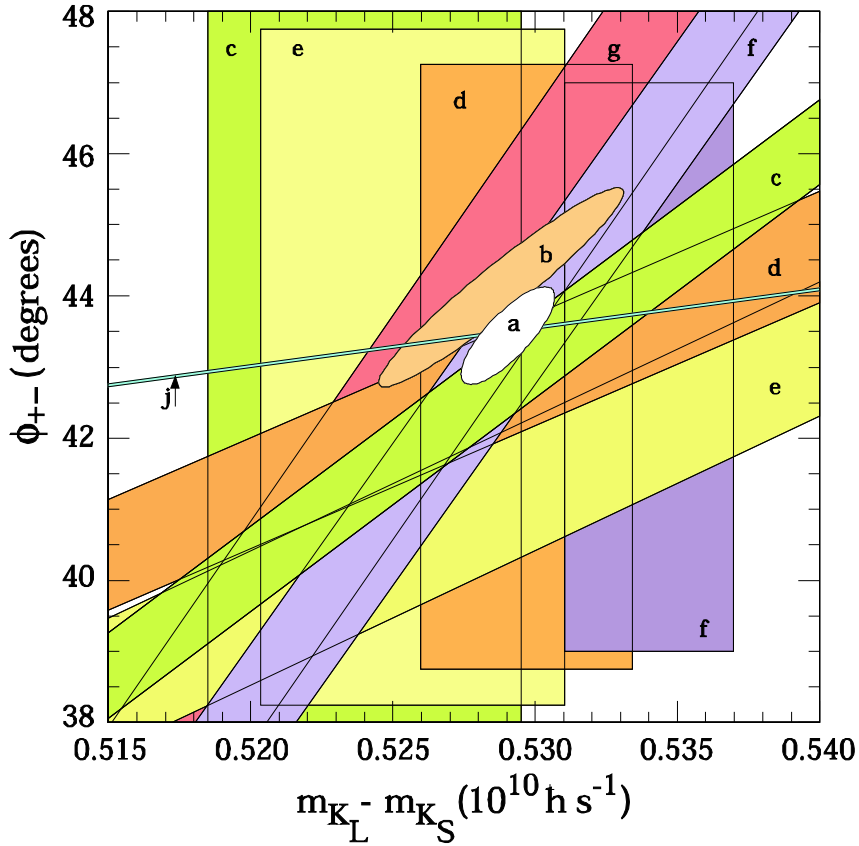


Table 1: References, Document ID's, and sources corresponding to the letter labels in the figures. The data are given in the ϕ_{+-} and Δm sections of the K_L Particle Listings, and the τ_S section of the K_S Particle Listings.

Label	Source	PDG Document ID	Ref.
a	this review	OUR FIT	
b	FNAL KTeV	ALAVI-HARATI 03	[8]
c	CERN CPLEAR	APOSTOLAKIS 99C	[9]
d	FNAL E773	SCHWINGENHEUER 95	[10]
e	FNAL E731	GIBBONS 93,93C	[11,12]
f	CERN	GEWENIGER 74B,74C	[13,14]
g	CERN NA31	CAROSI 90	[15]
h	CERN NA48	LAI 02C	[16]
i	CERN NA31	BERTANZA 97	[17]
j	this review	SUPERWEAK 04	

- **New KTeV data is shown as tan ellipse (b).**
- **When first published, the tan ellipse was much thinner than shown here, causing a very poor fit.**
- **PDG helped them track down their error: Erratum resulted.**

Erratum: Measurements of Direct CP Violation, CPT Symmetry, and Other Parameters in the Neutral Kaon System

[Phys. Rev. D 67, 012005 (2003)]

(The KTeV Collaboration)

(Dated: January 28, 2004)

PACS numbers:

A computational mistake [1] led to incorrect correlation coefficients for the fit without CPT assumptions (see Table XIII and Fig. 31 in Appendix D). The corrected correlation coefficients are given in Table I. The updated 1σ contours for statistical and total uncertainties for the measurements of Δm, τ_S and ϕ_{+-} are shown in Figure 1.

TABLE I: Total uncertainties and correlation coefficients for Δm, τ_S and ϕ_{+-} measured without CPT assumption.

	Δm	τ_S	ϕ_{+-}
Total Error	$43 \times 10^6 \hbar s$	0.13×10^{-12}s	1.40°
Correlation coefficients			
Δm	1.		
τ_S	-0.840	1.	
ϕ_{+-}	+0.955	-0.871	1.

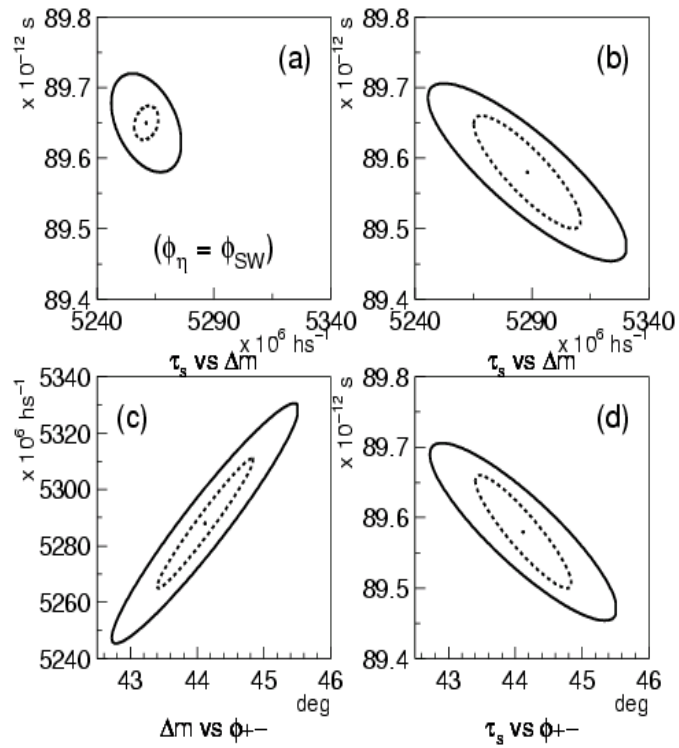


FIG. 1: 1σ contours of statistical uncertainty (dashed) and total uncertainty (solid) for (a) Δm-τ_S fit (combined charged+neutral), and for (b)-(d) correlations from the ϕ_{+-} fit.

[1] We would like to thank T. Trippe for pointing out this error.

Related improvements to RPP data handling

- In 2002 edition
  - Dependencies, correlations in fit input
- Added for 2004 edition
  - Dependency footnotes are automatically generated
  - Different fits can use overlapping subsets of data
    - e.g. fit assuming CPT, fit not assuming CPT
    - Multiple fit results now automatically appear in listings
  - Scale factor handling with correlations is improved
    - This issue needs further investigation before 2006
  - Plots now include inputs with correlations: ellipses

Example of new data handling features

ϕ_{+-}, PHASE of η_{+-}

VALUE (°)	EVTS	DOCUMENT ID	TECN	COMMENT
43.52±0.06 OUR FIT	Error includes scale factor of 1.3. Assuming *CPT*			
43.4 ±0.7 OUR FIT	Error includes scale factor of 1.3. Not assuming *CPT*			
44.12±0.72±1.20		[94] ALAVI-HARATI03	KTEV	Not assuming *CPT*
42.9 ±0.6 ±0.3	70M	[95] APOSTOLA... 99C	CPLR	K^0-$\overline{K}^0$ asymmetry

[95] APOSTOLAKIS 99C measures $\phi_{+-} = (43.19 \pm 0.53 \pm 0.28) + 300\,[\Delta m - 0.5301]$ (°). We have adjusted the measurement to use our best values of ($\Delta m = 0.5292 \pm 0.0010$) ($10^{10}\ \hbar\ s^{-1}$). Our first error is their experiment's error and our second error is the systematic error from using our best values.

Outlook

- V_{us} all NEW: EXP. and TH. (beta decay no problem)
- To reorganize the slope parameters in $K_L \to l^+l^-\gamma$,$K_L \to e^+e^-\mu^+\mu^-$
- In $\Gamma(K^+ \to \pi^+\pi^0\gamma)$ NOW only IB and DE : we need to distinguish in DE Interference terms and pure magnetic terms
- PDG CP violation fits improved (KTeV aknowledges independent check)