$K^{\pm}$ – THIS IS PART 1 OF 4

To reduce the size of this section's PostScript file, we have divided it into four PostScript files. We present the following index:

PART 1

Page #	Section name
1	Note on the charged kaon mass
4	Mass
5	Mean life

PART 2

Page #	Section name
7	Note on the rare kaon decays
13	Decay modes
14	Decay rates

PART 3

Page #	Section name
16	Branching ratios
24	Rare or forbidden modes
26	Longitudinal polarization of emitted μ^+

PART 4

Page #	Section name
27	Note on Dalitz plot parameters for $K \to 3\pi$ decays
28	Energy dependence of $K^{\pm}$ Dalitz plot
31	Note on $K^{\pm}_{\ell 3}$ and $K^0_{\ell 3}$ form factors
34	$K^{\pm}_{\ell 3}$ form factors
38	$K^{\pm} \to \ell^{\pm}\nu\gamma$ form factors
39	References

$K^\pm$ $I(J^P) = \frac{1}{2}(0^-)$

THE CHARGED KAON MASS

(by T.G. Trippe, Lawrence Berkeley National Laboratory)

The average of the six charged kaon mass measurements which we use in the Particle Listings is

$$m_{K^\pm} = 493.677 \pm 0.013 \text{ MeV (S = 2.4)} , \quad (1)$$

where the error has been increased by the scale factor S. The large scale factor indicates a serious disagreement between different input data. The average before scaling the error is

$$m_{K^\pm} = 493.677 \pm 0.005 \text{ MeV} ,$$
$$\chi^2 = 22.9 \text{ for 5 D.F., Prob. } = 0.04\% , \quad (2)$$

where the high χ^2 and correspondingly low χ^2 probability further quantify the disagreement.

The main disagreement is between the two most recent and precise results,

$m_{K^\pm}$ =	493.696 ± 0.007 MeV	DENISOV 91
$m_{K^\pm}$ =	493.636 ± 0.011 MeV (S = 1.5)	GALL 88
Average =	493.679 ± 0.006 MeV	

$$\chi^2 = 21.2 \text{ for 1 D.F., Prob. } = 0.0004\% , \quad (3)$$

both of which are measurements of x-ray energies from kaonic atoms. Comparing the average in Eq. (3) with the overall average in Eq. (2), it is clear that DENISOV 91 and GALL 88 dominate the overall average, and that their disagreement is responsible for most of the high χ^2.

The GALL 88 measurement was made using four different kaonic atom transitions, K^- Pb $(9 \to 8)$, K^- Pb $(11 \to 10)$, K^- W $(9 \to 8)$, and K^- W $(11 \to 10)$. The $m_{K^\pm}$ values they obtain from each of these transitions is shown in the Particle Listings and in Fig. 1. Their K^- Pb $(9 \to 8)$ $m_{K^\pm}$is below and somewhat inconsistent with their other three transitions. The average of their four measurements is

$$m_{K^\pm} = 493.636 \pm 0.007 ,$$
$$\chi^2 = 7.0 \text{ for 3 D.F., Prob. } = 7.2\% . \quad (4)$$

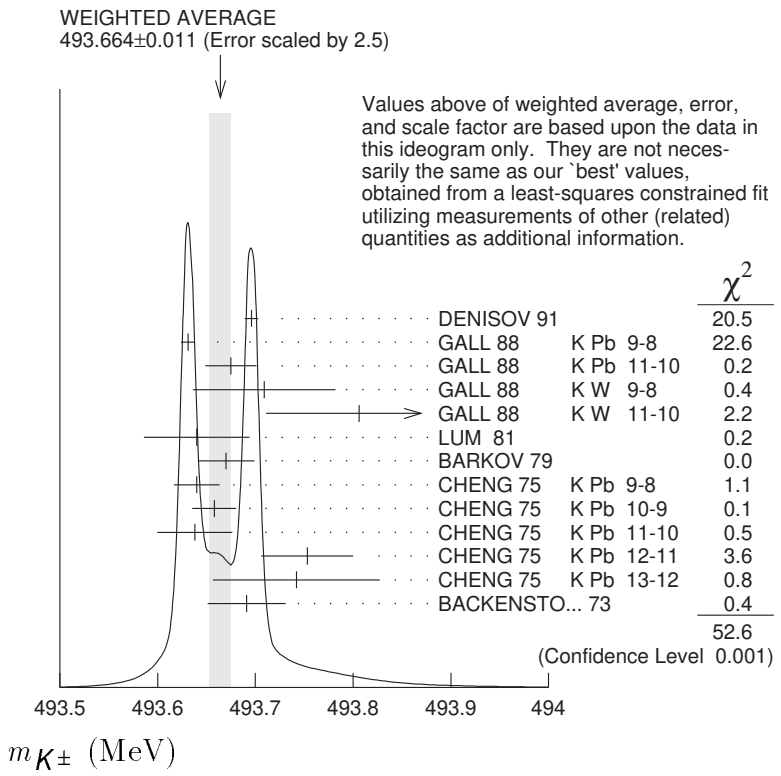


Figure 1: Ideogram of $m_{K^\pm}$ mass measurements. GALL 88 and CHENG 75 measurements are shown separately for each transition they measured.

This is a low but acceptable χ^2 probability so, to be conservative, GALL 88 scaled up the error on their average by S=1.5 to obtain their published error ± 0.011 shown in Eq. (3) above and used in the Particle Listings average.

The ideogram in Fig. 1 shows that the DENISOV 91 measurement and the GALL 88 K^- Pb $(9 \to 8)$ measurement yield two well-separated peaks. One might suspect the GALL 88 K^- Pb $(9 \to 8)$ measurement since it is responsible both for the internal inconsistency in the GALL 88 measurements and the disagreement with DENISOV 91.

To see if the disagreement could result from a systematic problem with the K^- Pb $(9 \to 8)$ transition, we have separated the CHENG 75 data, which also used K^- Pb, into its separate transitions. Figure 1 shows that the CHENG 75 and GALL 88 K^- Pb $(9 \to 8)$ values are consistent, suggesting the possibility of a common effect such as contaminant nuclear γ rays near the K^- Pb $(9 \to 8)$ transition energy, although the CHENG 75 errors are too large to make a strong conclusion. The average

of all 13 measurements has a χ^2 of 52.6 as shown in Fig. 1 and the first line of Table 1, yielding an unacceptable χ^2 probability of 0.00005%. The second line of Table 1 excludes both the GALL 88 and CHENG 75 measurements of the K^- Pb $(9 \to 8)$ transition and yields a χ^2 probability of 43%. The third [fourth] line of Table 1 excludes only the GALL 88 K^- Pb $(9 \to 8)$ [DENISOV 91] measurement and yields a χ^2 probability of 20% [8.6%]. Table 1 shows that removing both measurements of the K^- Pb $(9 \to 8)$ transition produces the most consistent set of data, but that excluding only the GALL 88 K^- Pb $(9 \to 8)$ transition or DENISOV 91 also produces acceptable probabilities.

Table 1: $m_{K^\pm}$ averages for some combinations of Fig. 1 data.

$m_{K^\pm}$ (MeV)	χ^2	D.F.	Prob. (%)	Measurements used
493.664 ± 0.004	52.6	12	0.00005	all 13 measurements
493.690 ± 0.006	10.1	10	43	no K^- Pb$(9\to8)$
493.687 ± 0.006	14.6	11	20	no GALL 88 K^- Pb$(9\to8)$
493.642 ± 0.006	17.8	11	8.6	no DENISOV 91

Yu.M. Ivanov, representing DENISOV 91, has estimated corrections needed for the older experiments because of improved ^{192}Ir and ^{198}Au calibration γ-ray energies. He estimates that CHENG 75 and BACKENSTOSS 73 $m_{K^\pm}$ values could be raised by about 15 keV and 22 keV, respectively. With these estimated corrections, Table 1 becomes Table 2. The last line of Table 2 shows that if such corrections are assumed, then GALL 88 K^- Pb $(9 \to 8)$ is inconsistent with the rest of the data even when DENISOV 91 is excluded. Yu.M. Ivanov warns that these are rough estimates. Accordingly, we do not use Table 2 to reject the GALL 88 K^- Pb $(9 \to 8)$ transition, but we note that a future reanalysis of the CHENG 75 data could be useful because it might provide supporting evidence for such a rejection.

The GALL 88 measurement uses a Ge semiconductor spectrometer which has a resolution of about 1 keV, so they run the risk of some contaminant nuclear γ rays. Studies of γ rays following stopped π^- and Σ^- absorption in nucleii (unpublished) do not show any evidence for contaminants according to GALL 88 spokesperson, B.L. Roberts. The DENISOV 91 measurement uses a crystal diffraction spectrometer with a

Table 2: $m_{K^\pm}$ averages for some combinations of Fig. 1 data after raising CHENG 75 and BACKENSTOSS 73 values by 0.015 and 0.022 MeV respectively.

$m_{K^\pm}$ (MeV)	χ^2	D.F.	Prob. (%)	Measurements used
493.666 ± 0.004	53.9	12	0.00003	all 13 measurements
493.693 ± 0.006	9.0	10	53	no K^- Pb(9→8)
493.690 ± 0.006	11.5	11	40	no GALL 88 K^- Pb(9→8)
493.645 ± 0.006	23.0	11	1.8	no DENISOV 91

resolution of 6.3 eV for radiation at 22.1 keV to measure the 4f-3d transition in K^- ^{12}C. The high resolution and the light nucleus reduce the probability for overlap by contaminant γ rays, compared with the measurement of GALL 88. The DENISOV 91 measurement is supported by their high-precision measurement of the 4d-2p transition energy in π^- ^{12}C, which is good agreement with the calculated energy.

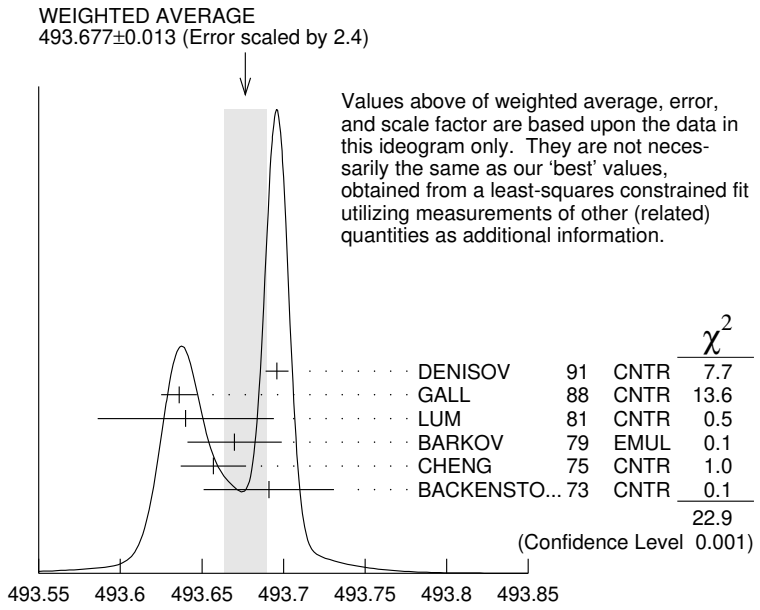
While we suspect that the GALL 88 K^- Pb (9 → 8) measurements could be the problem, we are unable to find clear grounds for rejecting it. Therefore, we retain their measurement in the average and accept the large scale factor until further information can be obtained from new measurements and/or from reanalysis of GALL 88 and CHENG 75 data.

We thank B.L. Roberts (Boston Univ.) and Yu.M. Ivanov (Petersburg Nuclear Physics Inst.) for their extensive help in understanding this problem.

$K^\pm$ MASS

VALUE (MeV)	DOCUMENT ID		TECN	CHG	COMMENT
493.677±0.016 OUR FIT Error includes scale factor of 2.8.					
493.677±0.013 OUR AVERAGE Error includes scale factor of 2.4. See the ideogram below.					
493.696±0.007	[1] DENISOV	91	CNTR	–	Kaonic atoms
493.636±0.011	[2] GALL	88	CNTR	–	Kaonic atoms
493.640±0.054	LUM	81	CNTR	–	Kaonic atoms
493.670±0.029	BARKOV	79	EMUL	±	$e^+e^- \to K^+K^-$
493.657±0.020	[2] CHENG	75	CNTR	–	Kaonic atoms
493.691±0.040	BACKENSTO...73		CNTR	–	Kaonic atoms
• • • We do not use the following data for averages, fits, limits, etc. • • •					
493.631±0.007	GALL	88	CNTR	–	K^- Pb (9→ 8)
493.675±0.026	GALL	88	CNTR	–	K^- Pb (11→ 10)
493.709±0.073	GALL	88	CNTR	–	K^- W (9→ 8)
493.806±0.095	GALL	88	CNTR	–	K^- W (11→ 10)
493.640±0.022±0.008	[3] CHENG	75	CNTR	–	K^- Pb (9→ 8)
493.658±0.019±0.012	[3] CHENG	75	CNTR	–	K^- Pb (10→ 9)
493.638±0.035±0.016	[3] CHENG	75	CNTR	–	K^- Pb (11→ 10)
493.753±0.042±0.021	[3] CHENG	75	CNTR	–	K^- Pb (12→ 11)
493.742±0.081±0.027	[3] CHENG	75	CNTR	–	K^- Pb (13→ 12)
493.662±0.19	KUNSELMAN	74	CNTR	–	Kaonic atoms
493.78 ±0.17	GREINER	65	EMUL	+	
493.7 ±0.3	BARKAS	63	EMUL	–	
493.9 ±0.2	COHEN	57	RVUE	+	

[1] Error increased from 0.0059 based on the error analysis in IVANOV 92.
[2] This value is the authors' combination of all of the separate transitions listed for this paper.
[3] The CHENG 75 values for separate transitions were calculated from their Table 7 transition energies. The first error includes a 20% systematic error in the noncircular contaminant shift. The second error is due to a ±5 eV uncertainty in the theoretical transition energies.



$m_{K^+} - m_{K^-}$

Test of *CPT*.

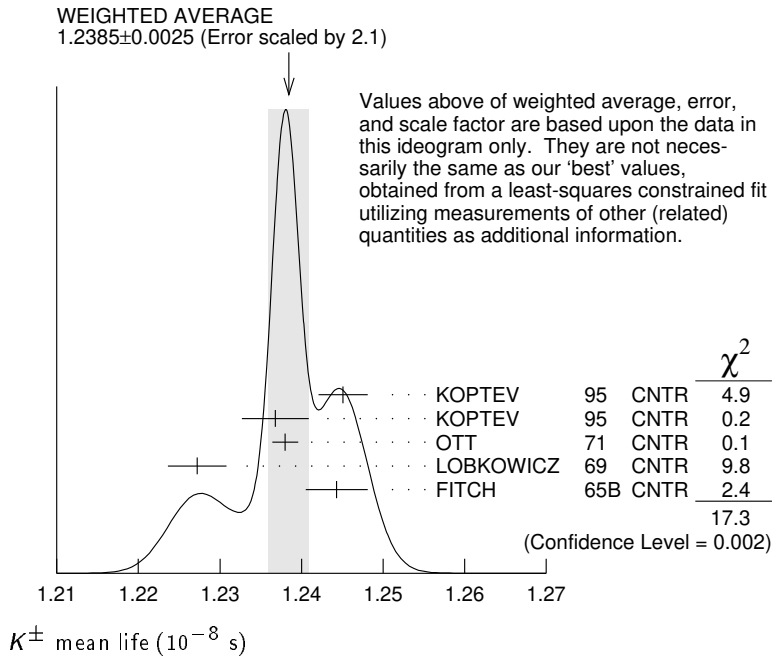
VALUE (MeV)	EVTS	DOCUMENT ID		TECN	CHG
−0.032±0.090	1.5M	[4] FORD	72	ASPK	±

[4] FORD 72 uses $m_{\pi^+} - m_{\pi^-} = +28 \pm 70$ keV.

$K^\pm$ MEAN LIFE

VALUE (10^{-8} s)	EVTS	DOCUMENT ID		TECN	CHG	COMMENT
1.2386±0.0024 OUR FIT Error includes scale factor of 2.0.						
1.2385±0.0025 OUR AVERAGE Error includes scale factor of 2.1. See the ideogram below.						
1.2451±0.0030	250k	KOPTEV	95	CNTR		*K* at rest, U target
1.2368±0.0041	150k	KOPTEV	95	CNTR		*K* at rest, Cu target
1.2380±0.0016	3M	OTT	71	CNTR	+	*K* at rest
1.2272±0.0036		LOBKOWICZ	69	CNTR	+	*K* in flight
1.2443±0.0038		FITCH	65B	CNTR	+	*K* at rest
• • • We do not use the following data for averages, fits, limits, etc. • • •						
1.2415±0.0024	400k	[5] KOPTEV	95	CNTR		*K* at rest
1.221 ±0.011		FORD	67	CNTR	±	
1.231 ±0.011		BOYARSKI	62	CNTR	+	
1.25 $^{+0.22}_{-0.17}$		BARKAS	61	EMUL		
1.27 $^{+0.36}_{-0.23}$	51	BHOWMIK	61	EMUL		
1.31 ±0.08	293	NORDIN	61	HBC	−	
1.24 ±0.07		NORDIN	61	RVUE	−	
1.38 ±0.24	33	FREDEN	60B	EMUL		
1.21 ±0.06		BURROWES	59	CNTR		
1.60 ±0.3	52	EISENBERG	58	EMUL		
0.95 $^{+0.36}_{-0.25}$		ILOFF	56	EMUL		

[5] KOPTEV 95 report this weighted average of their U-target and Cu-target results, where they have weighted by $1/\sigma$ rather than $1/\sigma^2$.



$(\tau_{K^+} - \tau_{K^-}) / \tau_{average}$

This quantity is a measure of *CPT* invariance in weak interactions.

VALUE (%)	*DOCUMENT ID*		*TECN*
0.11 ±0.09 OUR AVERAGE	Error includes scale factor of 1.2.		
0.090± 0.078	LOBKOWICZ	69	CNTR
0.47 ±0.30	FORD	67	CNTR