Baryon semileptonic Decays

Review Hyperon 99, Fermilab.

- Hyperon semilep. decays (HSD)

  $\Sigma^{\pm} \longrightarrow \Lambda e \nu$

  $\Lambda \to p e \nu$, $\Sigma^{-} \to n e \nu$, $\Xi^{-} \longrightarrow \Lambda e \nu$, $\Sigma^{0} e \nu$

  $\Xi^{0} \to \Sigma^{+} e \nu$ in progress (see Alavi-Harati talk)

- Charm baryon semilep. decays

  $\Lambda_c^{+} \to \Lambda e \nu$

- Free neutron beta decay

HSD

An overview: how good are the data?

	Precision of B.R	g_1/f_1	Precision of form. factors	Year last measurem.
$n \to pe\nu$	0.2%	1.2670 ± 0.0035	0.3%	'97
$\Sigma^+ \to \Lambda e\nu$	25%	not even quoted	—	'69
$\Sigma^- \to \Lambda e\nu$	5%	-0.010 ± 0.100 (f_1/g_1)	—	'82
$\Lambda \to pe\nu$	2%	0.718 ± 0.015	2%	'90
$\Sigma^- \to ne\nu$	3%	-0.340 ± 0.017	5%	'88
$\Xi^- \to \Lambda e\nu$	5%	0.250 ± 0.050	20%	'83
$\Xi^- \to \Sigma^0 e\nu$	20%	not even quoted	—	'83

Comparison with weak radiative decays

		m.m.	
$\Lambda \to p\gamma$	8.6%	μ_Λ	0.7%
$\Sigma^+ \to p\gamma$	4.1%	μ_{Σ^+}	0.4%
$\Xi^0 \to \Lambda\gamma$	15%	μ_{Σ^-}	2.2%
$\Xi^0 \to \Sigma^0\gamma$	11%	μ_{Ξ^0}	1.1%
$\Xi^- \to \Sigma^-\gamma$	18%	μ_{Ξ^-}	0.4%

Precision of decay rates (B.R.) are comparable, m.m. precision is much better than g_1/f_1 prec.

$\Delta S = 0$ HSD

$\Sigma^+ \to \Lambda e \nu$ of no practical use

$\Sigma^- \to \Lambda e \nu$

	exp	Cabibbo Th.* prediction	$\Delta \chi^2$
R	0.388 ± 0.018	0.451	<u>12.4</u>
$\alpha_{e\nu}$	-0.404 ± 0.044	-0.412	0.03
A	0.07 ± 0.07	0.06	0.02
B	0.85 ± 0.07	0.90	0.51

* Reported by Donoghue and Holstein Phys. Rev. D25, 706 (82)
G. and Kielanowski Phys. Lett 110B, 417 (82)

The only 3.5 σ discrepancy with the CT ever seen in HSD, due to the small error bars

This confirms that the CT is only approximate (in Cabibbo's own words: it was never intended to be exact), but it is a pretty good approximation for HSD.

$\Delta S = 1$ HSD

Here we do not discuss $\Xi^0 \to \Sigma^+ e \nu$, but recently detailed predictions have been produced by
Ratcliffe EPTCO-98-002 and
Flores, Jenkins, and Manohar UCSD/PTH 98-17

Rates and g_1/f_1 only do not use all information, better to use rates and angular coefficients.

Only $\Lambda \to p e \nu$, $\Sigma^- \to n e \nu$, and $\Xi^- \to \Lambda e \nu$ are useful. The data are

$\Lambda \to p e \nu$	$R =$	3.169 ± 0.058	$10^6\ s^{-1}$
	$\alpha_{e\nu} =$	-0.019 ± 0.013	
	$\alpha_e =$	0.125 ± 0.066	
	$\alpha_\nu =$	0.821 ± 0.060	
	$\alpha_p =$	-0.508 ± 0.065	
$\Sigma^- \to n e \nu$	$R =$	6.876 ± 0.235	$10^6\ s^{-1}$
	$\alpha_{e\nu} =$	0.347 ± 0.024	
	$\alpha_e =$	-0.519 ± 0.104	
	$\alpha_\nu =$	-0.230 ± 0.061	
	$\alpha_n =$	0.509 ± 0.102	
$\Xi^- \to \Lambda e \nu$	$R =$	3.36 ± 0.19	$10^6\ s^{-1}$
	$\alpha_{e\nu} =$	0.53 ± 0.10	
	$A =$	0.62 ± 0.10	

Resolving power of These data

A good way to assess it is to determine

$$V_{us}$$

of Cabibbo-Kobayashi-Maskawa matrix

There are only 4 decays That currently can determine V_{us}. These 3 HSD and K_{e3}.

K_{e3} is Theoretically more reliable and better measured, it gives
$$V_{us} = 0.2188 \pm 0.0016$$

To get V_{us} from The 3 HSD use 4 models

I relativistic QM — Schlumpf PR D51, 2262 (95)

II chiral pert. Theory with $O(m_s)$ correct. — Krause Helv. Phys. Acta 63, 3 (90)

III non-relat. Q-bag model with wave function mismatch and c.m. corrections. — Donoghue, Holstein, and Klimt PR D35, 934 (87)

IV Same as II, but with $O(m_s^{3/2})$ correct. — Anderson and Luty PR D47, 4975 (93)

The choice of These models is That They all calculate 2nd order SU_3 breaking to f_1, and I and III also give predictions for g_1/f_1

Predictions for $f_1 / f_1(SU_3)$

	I	II	III	IV
$\to pe\nu$	0.976	0.943	0.987	1.024
$^- \to ne\nu$	0.975	0.987	0.987	1.100
$^- \to \Lambda e\nu$	0.976	0.957	0.987	1.059

Predictions for $g_1 / g_1(SU_3)$

	I	II	III	IV
$\to pe\nu$	1.072	–	1.050	–
$\Sigma^- \to ne\nu$	1.056	–	1.040	–
$\Xi^- \to \Lambda e\nu$	1.072	–	1.003	–

These models make no predictions for f_2 nor g_2

Criteria

A) V_{us} must be common (same value) to the 3 HSD

B) The data must be well reproduced

C) Comparison with K_{e3} V_{us}

Models I and III

	I : V_{us}	χ^2	III : V_{us}	χ^2
$\Lambda \to p e \nu$	0.2130 ± 0.0020	38.5	0.2153 ± 0.0020	26.4
$\Sigma^- \to n e \nu$	0.2318 ± 0.0040	9.0	0.2307 ± 0.0040	7.9
$\Xi^- \to \Lambda e \nu$	0.2434 ± 0.0068	1.4	0.2429 ± 0.0068	2.4

V_{us} is dispersed by more than 3σ's

Data is not well reproduced

Criteria (A) and (B) are not satisfied

Source of discrepancies are the g_1

Drop predictions for g_1, but keep predictions for f_1

Get g_i's from data

The 4 models can now be compared on equal footing

	I: V_{us}	II: V_{us}	III: V_{us}	IV: V_{us}
Λ	0.2291 ± 0.0036	0.2372 ± 0.0037	0.2265 ± 0.0035	0.2183 ± 0.0034
Σ^-	0.2349 ± 0.0049	0.2320 ± 0.0049	0.2320 ± 0.048	0.2082 ± 0.0044
Ξ^-	0.2349 ± 0.0106	0.2396 ± 0.0108	0.2323 ± 0.0105	0.2165 ± 0.0098

χ^2 for $\Lambda = 10.7$, for $\Sigma^- = 7.8$, for $\Xi^- \sim 0$

always ↑

Criterion satisfied	↑	↑	↑	↑
(A)	O.K.	O.K.	O.K.	O.K.
(B)	more or less	more or less	more or less	more or less
(C)	no	no	no	yes

In contrast IV is in very good agreement

$$V_{us} = 0.2188 \pm 0.0016$$

Conclusion

Experiment is in better shape than theory and has good resolving power, but cannot measure induced f.f. with useful precision (signs and small magnitudes of g_2). Also,

$$|f_1|_{SB} > |f_1|_{CVC}$$

Theory seems to control better and probably well the vector-current sector,
the axial-vector one is qualitatively O.K., but quantitatively is not satisfactory

Reminder

$|V_{us} f_1|$ is the only experimentally accessible quantity. Separating this product into V_{us} and f_1 is a theoretical problem only

Effects of induced form factors f_2 and g_2

Allow for changes in steps of ± 0.10 and ± 0.20

f_2 has no perceptible effect on V_{us}

g_2 has a " " " "

in $\Lambda \to pe\bar{\nu}$ χ^2 reduced if $g_2 \sim +(0.10-0.20)$

" $\Sigma^- \to ne\bar{\nu}$ " " " $g_2 \sim -(0.10-0.20)$

" $\Xi^- \to \Lambda e\bar{\nu}$ no sensitivity at all.

α_ν in $\Lambda \to pe\bar{\nu}$ always contributes $\Delta\chi^2 \sim 7$, it requires large g_2, which is not readily acceptable.

Average values of V_{us}

	I	II	III	IV
V_{us}	0.2348 ± 0.0028	0.2392 ± 0.0028	0.2321 ± 0.0027	0.2176 ± 0.0026

I, II, III more than 5 σ's away from

$V_{us} = 0.2188 \pm 0.0016$ of K_{e3}

Charm baryon semileptonic decays

4 semileptonic decays have been detected so far

$\Xi_c^+ \to \Xi_0 e \nu$ seen ('96)

$\Xi_c^0 \to \Xi^- e \nu$ seen ('95)

and measured

	B.r.	α_e
$\Lambda_c^+ \to \Lambda \mu \nu$	$(2.0 \pm 0.7)\%$	
$\Lambda_c^+ \to \Lambda e \nu$	$(2.1 \pm 0.6)\%$	$-0.82^{+0.11}_{-0.07}$

Discuss $\Lambda_c^+ \to \Lambda e \nu$

Its decay rate is currently

$$R = (9.6 \pm 2.9) \times 10^{10}\, s^{-1}$$

Back in '84 (first measurement) it was

$$(6.1 \pm 4.6) \times 10^{10}\, s^{-1}$$

Cabibbo Theory is no longer a good approximation. It predicts an order of magnitude higher B.R. $\sim$ 15[illegible]

Theoretical predictions

The have been made over the past 20-23 years, Review by Körner, Krämer, and Pirjol, Prog. Nucl. Part. Phys. 33, 787 ('94)

R	Buras	Gavela	NRQM	Singleton	HQET
a)	60	15	17	10	22
b)	20	5	5.6	10	7.3

R in $10^{10}\,s^{-1}$

(a) original predictions

(b) predictions when one applies a 1/3 suppression factor due to heavy quark symmetry (spin-flavor suppression factor leading to diquark states)

There are more predictions

NRQM, spectator model with QCD corrections

$$R = 11.2 \times 10^{10}\,s^{-1}$$

Hussain and G., PR D45, 3266 (92)

NRQM with heavy quark sym., revised by H.Y. Cheng, hep-ph/9608445

$$R = 7.1 \times 10^{10}\, s^{-1}$$

Full QCD sum rules (improve over HQET infinite mass limit), Marques de Carvalho, et al. PR D60, 034001 (99)

Method 1 $\quad R = (13.2 \pm 1.8) \times 10^{10}\, s^{-1}$

Method 2 $\quad R = (20.7 \pm 3.5) \times 10^{10}\, s^{-1}$

Conclusions

Theoretical predictions still vary a lot, but they tend to agree with higher values than obtained before

Experimentally, even if R is still loosely determined it already put important restrictions on predictions, for ex. the 1/3 recipe to introduce heavy quark sym. is ruled out

Charm baryons semileptonic decays [illegible]

Free neutron beta decay.

There are 4 observables measured R, $d_{e\nu}$, d_e, d_ν

Only R and d_e are really constraining.

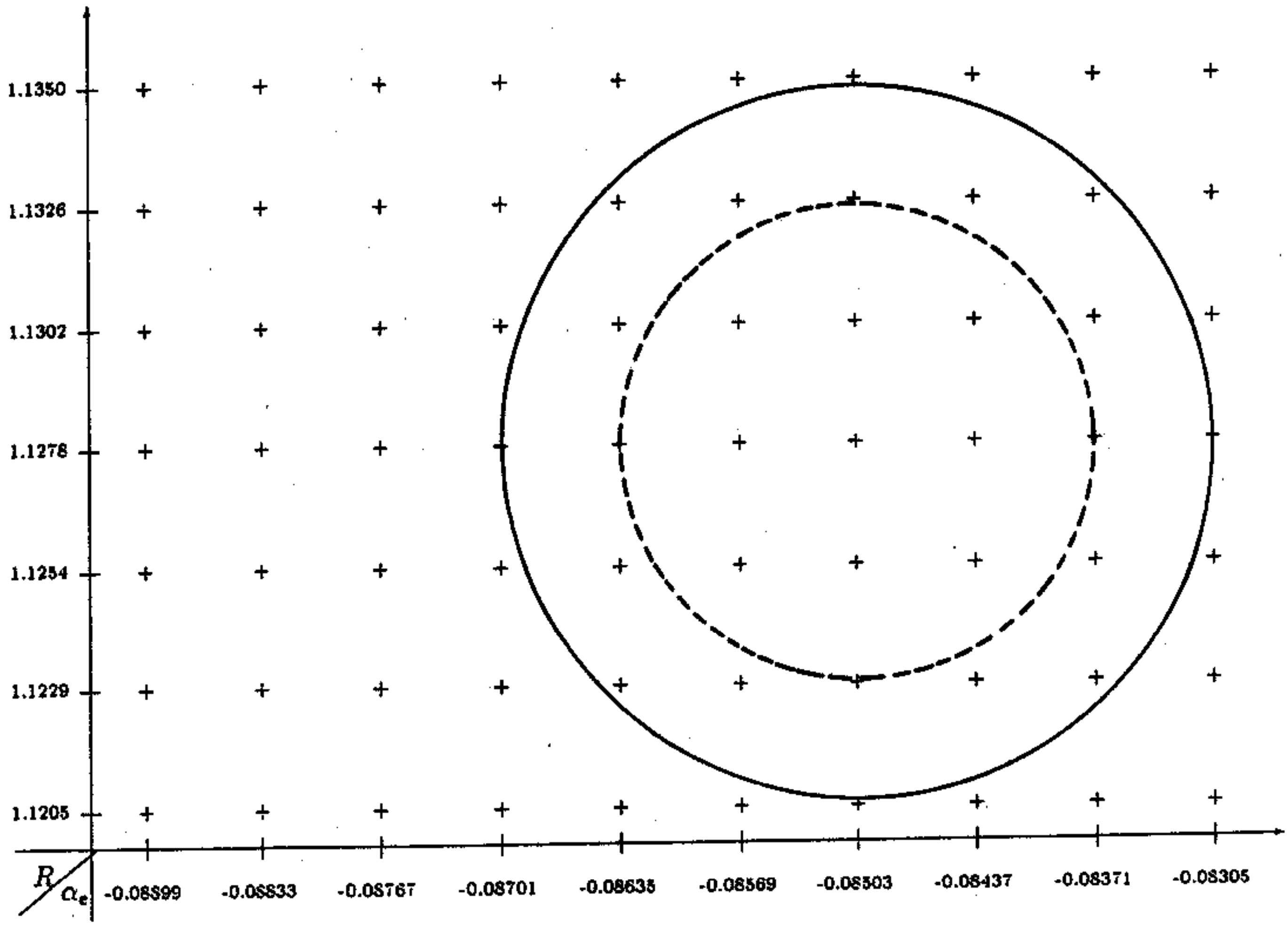
(several experiments) $R = 1.1278 \pm 0.0024$ (in $10^{-3} s^{-1}$)

(3 expt until Sept.'97) $\alpha_e = -0.08503 \pm 0.00066$

g_1 is difficult to calculate precisely, but otherwise theoretical uncertainties are under control down to 5 parts in 10^{-4}

d_e determines $\lambda = g_1/h_1 = -1.2624 \pm 0.0024$
(0.2%)

One can plot the experimental region of the above R and d_e in an (R, d_e) plane (Fig. 1)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R
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-0.08833
-0.08767
-0.08701
-0.08635
-0.08569
-0.08503
-0.08437
-0.08371
-0.08305

Fig. 1

V_{ud}

Since g_A determines λ, the only free parameter in free $n \to p e \bar{\nu}$ is V_{ud}

The 3 expts. give

$$V_{ud} = 0.9793 \pm 0.0019$$

Superallowed nuclear β decays give

$$V_{ud} = 0.9736 \pm 0.0005$$ but values as high as $V_{ud} = 0.9750 \pm 0.0005$ are also discussed

Unitarity of Cabibbo-Kobayashi-Maskawa gives

$$V_{ud} = 0.9756 \pm 0.0004 \quad \text{or}$$

$$V_{ud} \in (0.9763, 0.9750) \text{ at } 90\% \text{ C.L.}$$

There is a clear discrepancy between free and nuclear β decays and free neutron V_{ud} is a little over 2σ's above the unitary V_{ud}

There is better way to study these data

The allowed region for the Standard Model

One needs something better to compare R and α_e with.

The state-of-the-art in experiments allows R and α_e error bars to be reduced to 1/10 of what they are today (Wilkinson, '94)

$$\sigma_R \rightarrow \frac{1}{10}\,\sigma_R$$

$$\sigma_{\alpha_e} \rightarrow \frac{1}{10}\,\sigma_{\alpha_e}$$

Then, the unitarity of CKM matrix defines a region in the (R, α_e) plane, within which the SM remains valid to 3 σ's

(Fig. 2)

and one can compared to the "current" experimental region (before sept '97)

(Fig. 3)

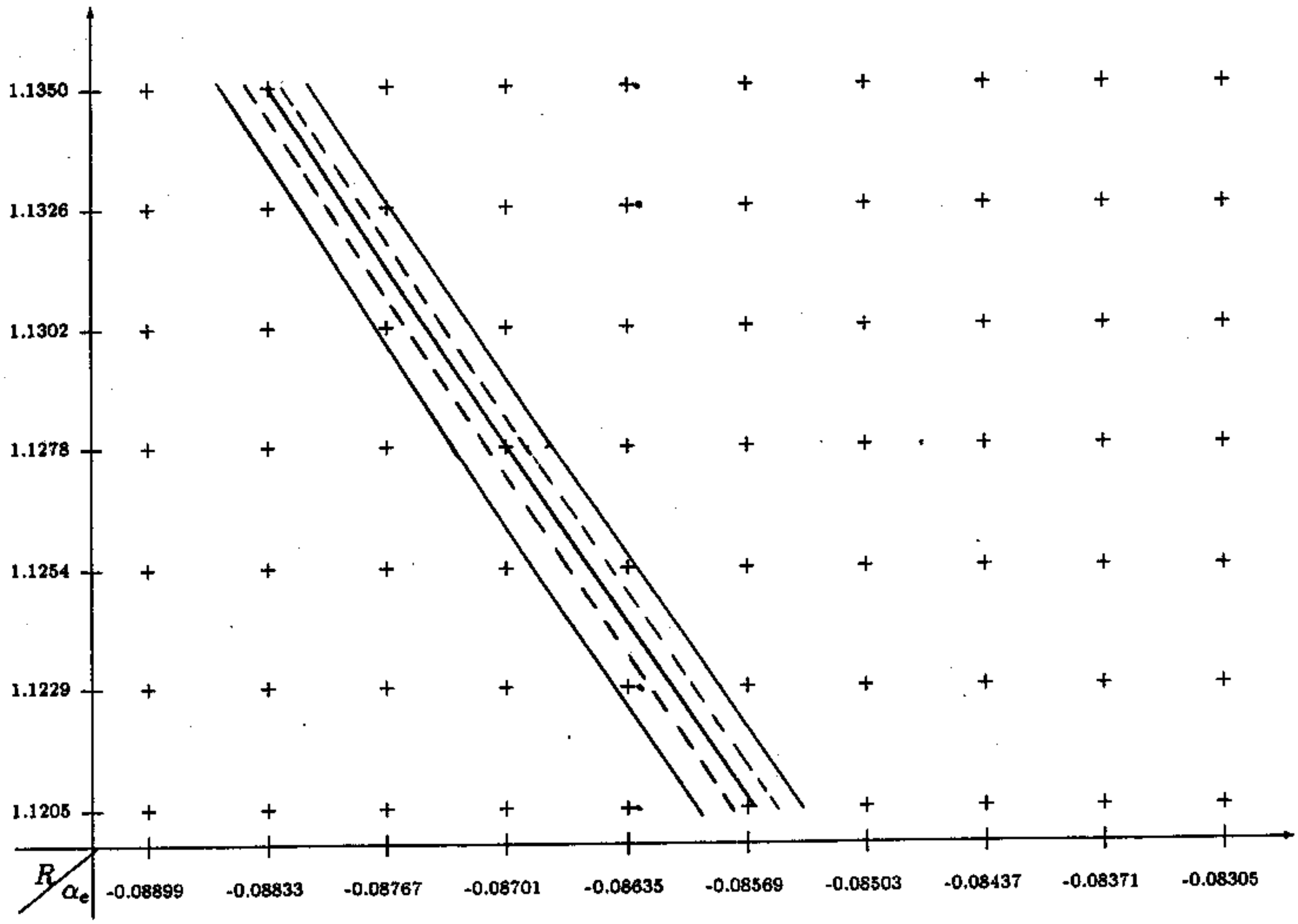
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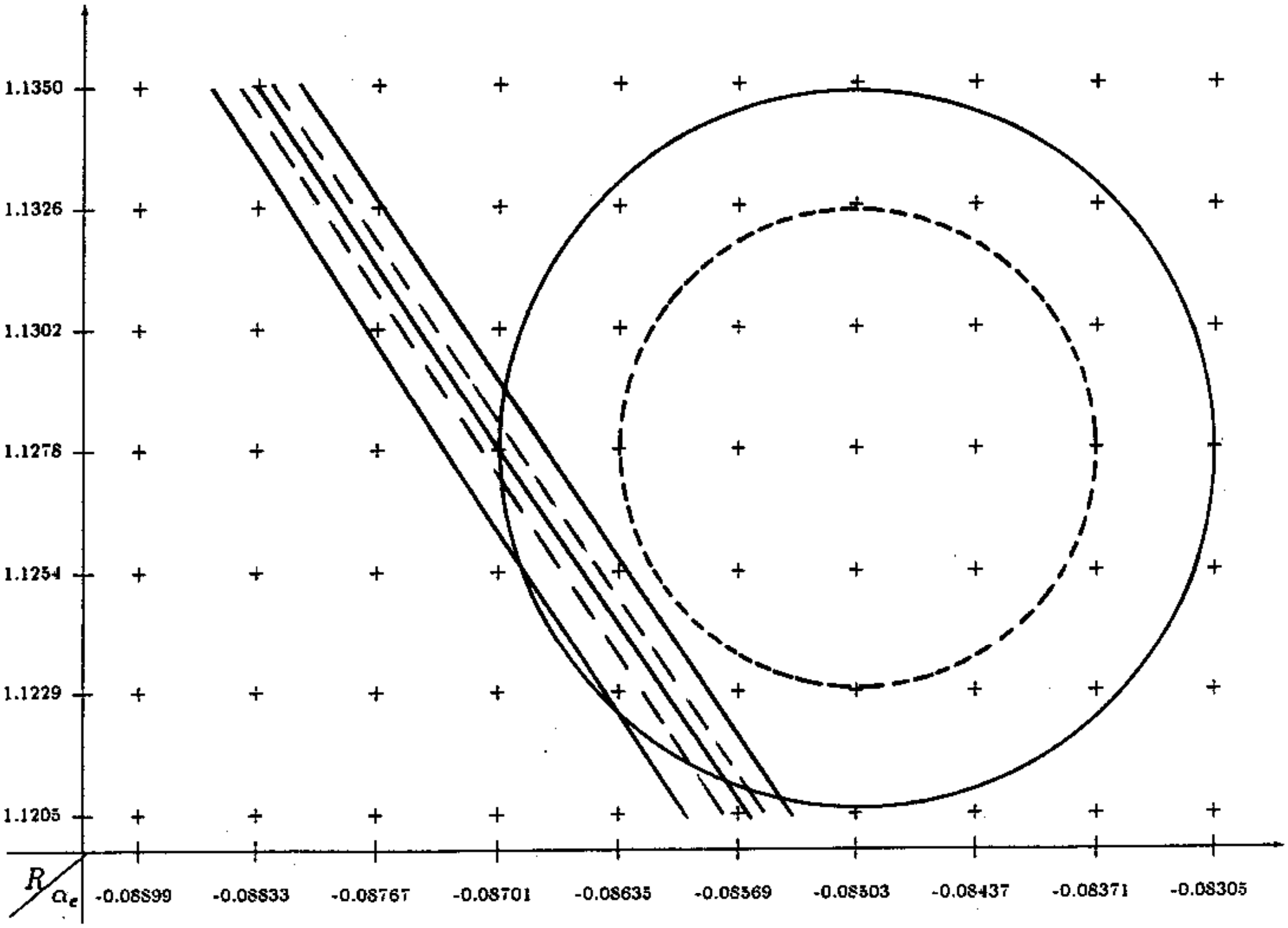
Fig. 2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-0.08305

Fig. 3

3 dimensions

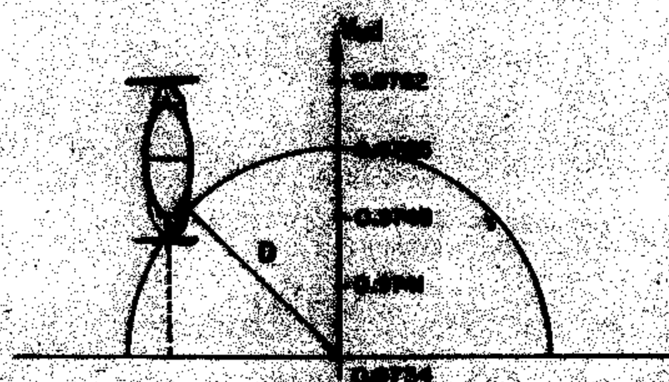
a 3rd axis for V_{ud} can be added,
the SM region becomes a Tube and
the experim. region becomes a sphere.

Allowing for the 90% C.L. of unitarity V_{ud}
one gets Fig. 4

The 3 experiments are [redacted] off the SM
tube at 3 σ's (negligible overlap)

or

Those experiments give a significant
signal for New Physics



Real life is more difficult

In sept. '97 a new result on α_e was reported (Abele et al. Phys. Lett. B407, 212 ('97))

$$\alpha_e = -0.08820 \pm 0.00081$$

or

$$\lambda = -1.2740 \pm 0.0030$$

for this experiment there corresponds

$$V_{ud} = 0.9709 \pm 0.0022$$

This time lower the unitarity V_{ud}

Its (R, α_e) region is given in Fig. 5 and it is in conflict with the previous average, Fig. 6, central values away by more than 3 σ's but it agrees better with the SM, Fig. 8

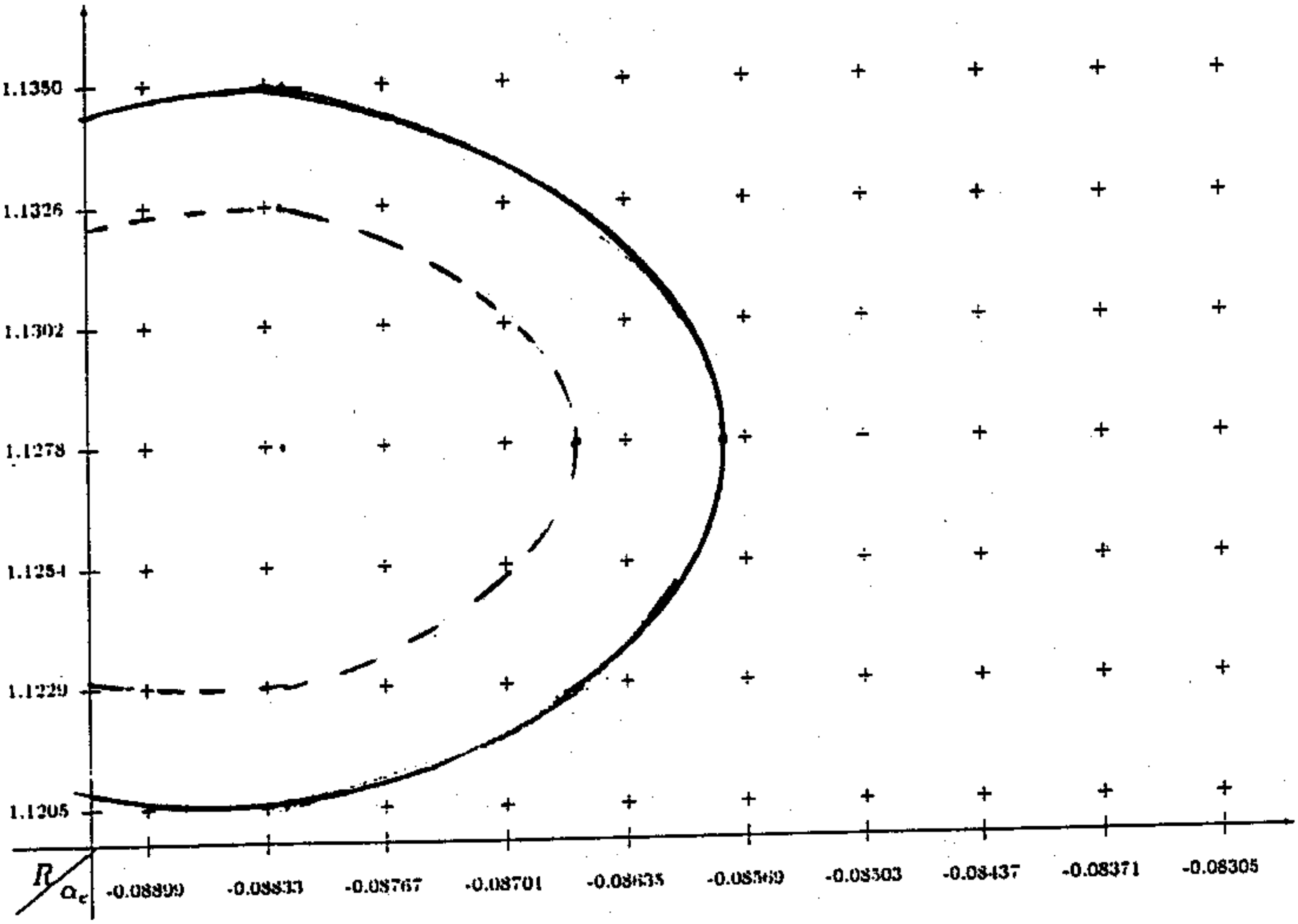

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Fig. 5

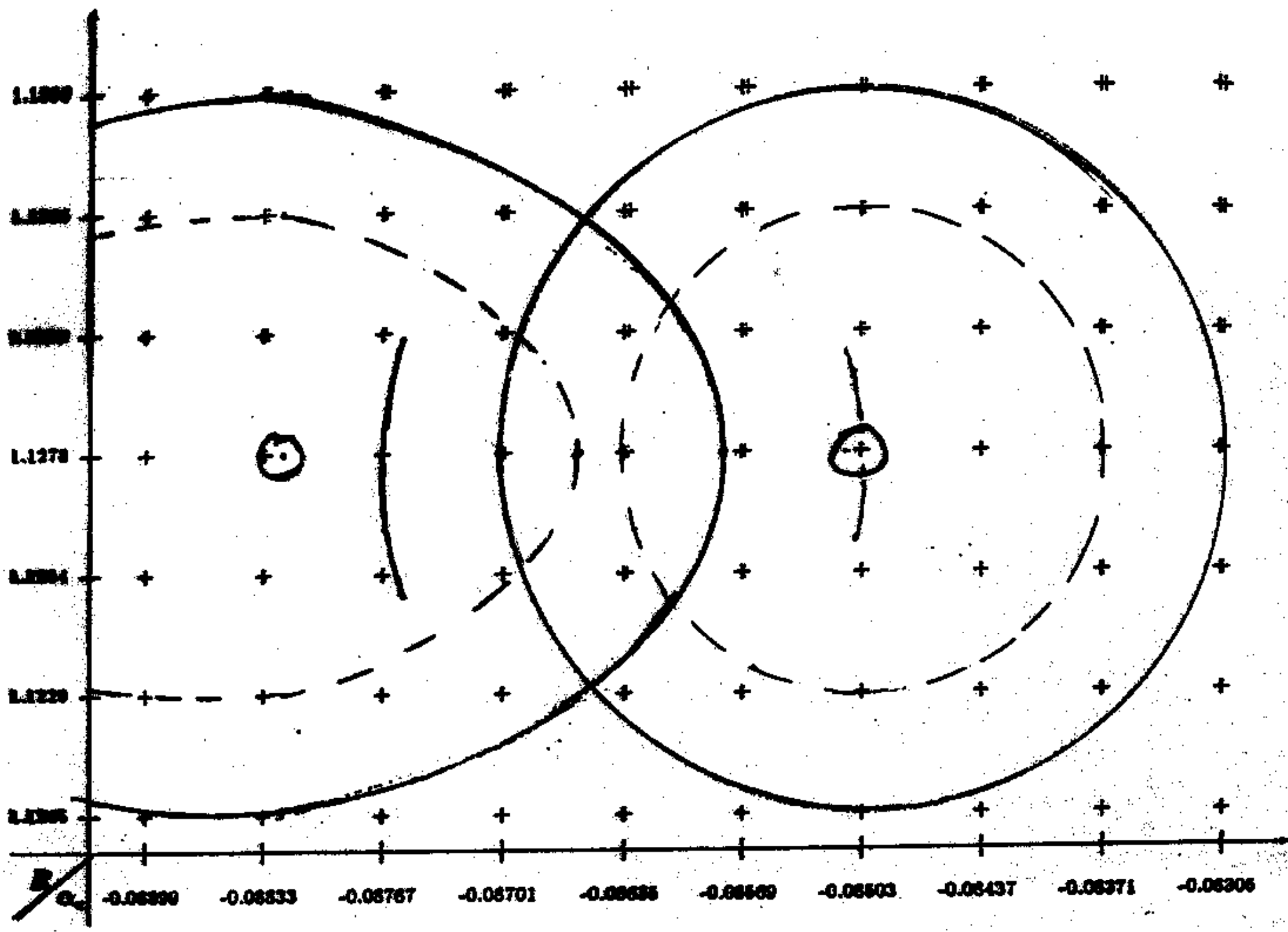

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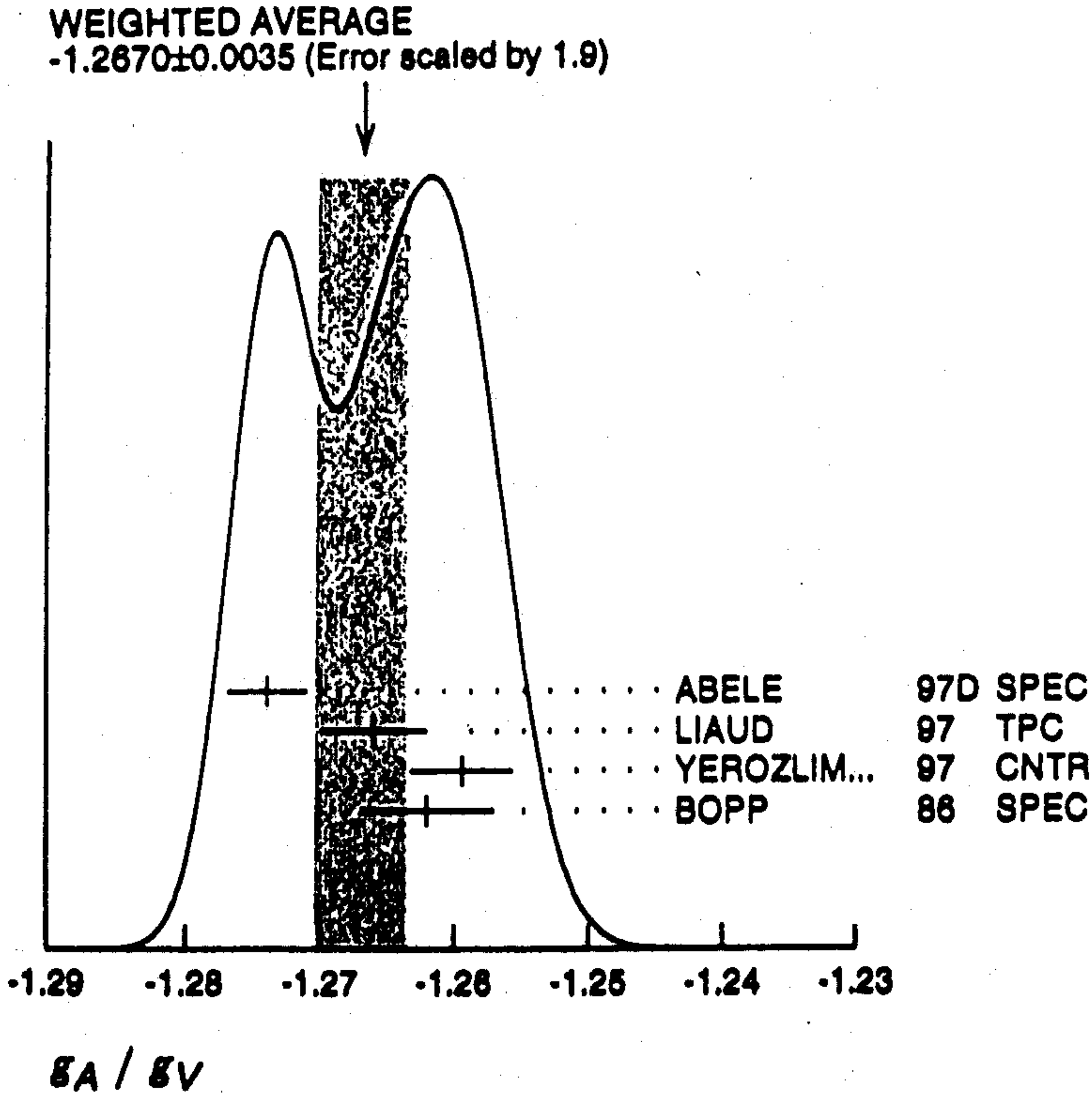
Fig. 6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LIAUD 97 TPC
YEROZLIM... 97 CNTR
BOPP 86 SPEC
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gA / gV

Fig. 7

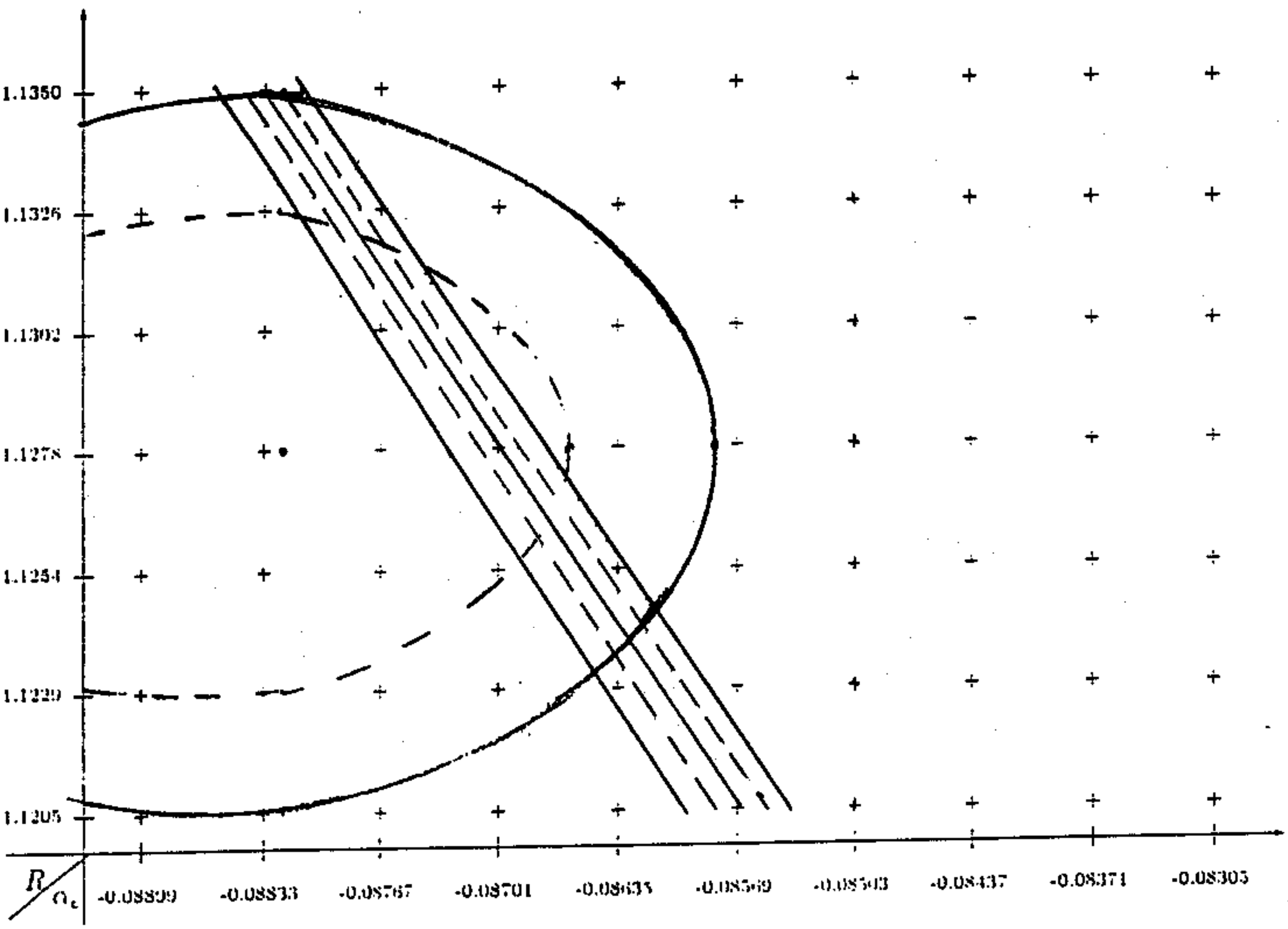

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Fig. 8

One should not average this last experiment with the 3 previous ones.

However, the average is in "perfect agreement" with the SM, Fig. 9

This situation is not unprecedented. Measuring R to the current precision was also afflicted by more the 3 σ's conflicts. History repeats itself, so do this time.

However eventually a unique value will be established with appreciable smaller error bars.

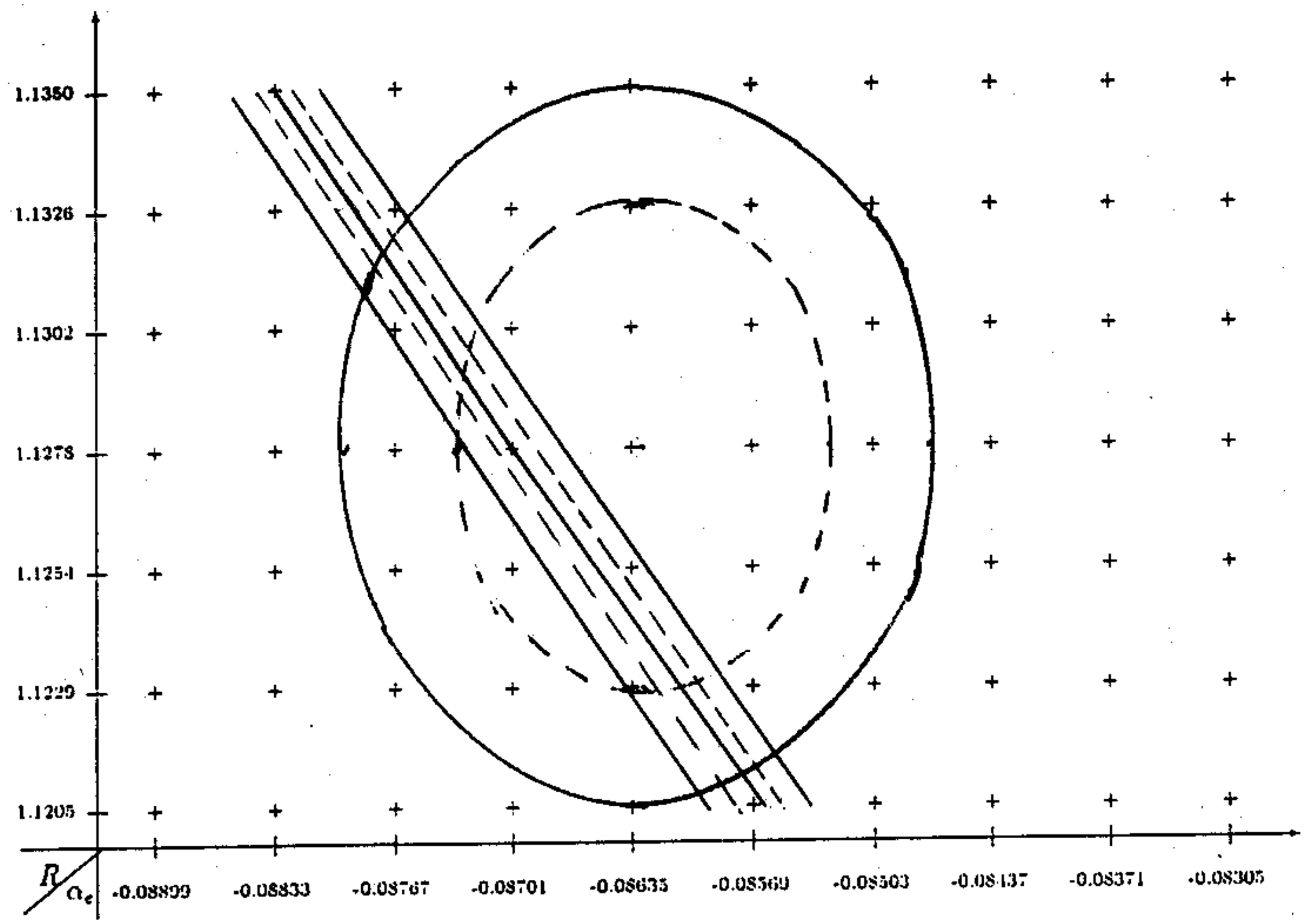
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Fig. 10

Precision required to see "new physics"

For example, if the average central value of the 2 of previous expts. The are close to the 4th were to be the real one, then one would reach this value when

$$\sigma_R \longrightarrow \frac{1}{3}\,\sigma_R$$

$$\sigma_{\alpha_e} \longrightarrow \frac{1}{3}\,\sigma_{\alpha_e}$$

at 3 σ's

Just reducing one or the other error bars is useless.

The reduction must be simultaneous.

Table II

Use less →

useless ↓

	$\alpha_e/1$	$\alpha_e/2$	$\alpha_e/3$	$\alpha_e/4$	$\alpha_e/5$	$\alpha_e/6$	$\alpha_e/7$	$\alpha_e/8$	$\alpha_e/9$	$\alpha_e/10$
$R/1$	9.52	10.56	11.05	11.27	11.33	11.40	11.44	11.47	11.50	11.51
	1.28	2.31	2.80	3.03	3.19	3.26	3.30	3.33	3.35	3.37
$R/2$	9.89	12.65	15.16	16.95	18.16	18.98	19.54	19.94	20.24	20.45
	1.64	4.41	6.91	8.71	[illegible]	10.82	11.40	11.79	12.10	12.32
$R/3$	9.96	13.58	17.87	21.83	25.12	27.66	29.63	31.15	32.30	33.20
	1.74	5.33	9.68	13.59	16.92	19.47	21.46	22.99	24.14	25.05
$R/4$	10.02	[illegible]	[illegible]	25.17	30.57	35.37	39.32	42.67	44.88	46.82
	1.78	5.75	[illegible]	[illegible]	22.32	27.16	31.10	34.49	36.55	38.43
$R/5$	10.04	14.23	[illegible]	[illegible]	[illegible]	41.46	47.64	53.12	55.28	54.78
	1.79	5.98	12.07	[illegible]	[illegible]	[illegible]	[illegible]	44.90	46.53	45.07
$R/6$	10.05	14.36	20.87	[illegible]	[illegible]	46.04	54.03	55.72	63.98	72.17
	1.80	6.11	12.62	20.56	29.15	37.79	45.73	46.14	54.90	63.52
$R/7$	10.05	14.44	[illegible]	29.78	39.43	49.41	58.15	64.68	67.80	73.60
	1.81	6.19	[illegible]	[illegible]	31.18	41.13	49.61	55.63	57.82	63.51
$R/8$	10.06	14.49	21.47	[illegible]	[illegible]	50.86	59.94	66.73	81.41	78.80
	1.81	6.24	13.23	[illegible]	[illegible]	42.29	50.92	56.97	72.55	69.10
$R/9$	10.06	14.53	21.64	30.97	41.87	53.82	61.80	77.73	85.21	88.69
	1.81	6.28	13.40	22.72	33.56	45.49	52.48	69.17	76.06	78.61
$R/10$	10.06	14.55	21.77	31.33	42.63	54.12	67.24	74.63	82.02	90.22
	1.82	6.31	[illegible]	[illegible]	34.33	50.61	58.61	64.92	71.44	79.72

Both error bars must be reduced simultaneously.

Fig. 10

Conclusions

Free neutron β decay is close to either

i) detecting new physics

or

ii) putting very stringent bounds on its existance

If (i) obtains we shall be lucky to see ourselves new physics, and if

(ii) obtains it will be a subject for our grand children or worse (new physics will not be accessible in our time, bad luck).

Summary

HSD

- Experiment is better than theory, 2^{nd} order SU_3 breaking is detected, induced "second class" are seen to be small, but are not yet precisely measurable (only sign and small size)
- Theory seems to be in better shape in the vector sector but is only qualitatively well, not quantitatively, in the axial-vector sector

Charm baryon semileptonic decays

- This subject is not even in its infancy,
- but, nevertheless, it already puts constraints on theoretical (difficult) predictions

Free neutron beta decay,

- Close to either detect new physics
  or
- put severe constraints on it.