1) Hyperons

- New Results

2) "The angle" and the CKM matrix

3) Hyperons

The future

Physics Motivation For Cascade Beta Decay

$\Xi^0 \rightarrow \Sigma^+ e^- \bar{\nu}$ (ssu $\rightarrow$ suu) $\qquad \Xi^0 \rightarrow \Sigma^+ \mu^- \bar{\nu}$

- SU(3) copy of $n \rightarrow p e \nu_e$ (ddu $\rightarrow$ duu)
- Another test of Cabibbo Model.
- Any flavor SU(3) symmetry breaking indications?
- Large V&A form factor amplitudes.
- ~ 100% equivalent polarized Ξ^0 beam .
- No competing two body decay with the same final state baryon

  ($\Xi^0 \not\rightarrow \Sigma^+ \pi^-$)

  Unique possibility to probe this kind of decay at KTeV

New results at Hyperon '99

Personal Selection

$\Xi^0 \to \Sigma^+ e^- \bar{\nu}$ (KTeV)

"The last hyperon beta decay"

Isospin breaking and Σ^0-Λ^0 mixing

(Gabriel Karl)

$\sigma_{tot}(\Sigma^* p)$ @ 800 GeV

(Selex)

Hyperon Polarization in Hyperon beams

(Theory + Experiment)

$$\Xi^0 \rightarrow \Sigma^+ + e^- + \bar{\nu}_e$$

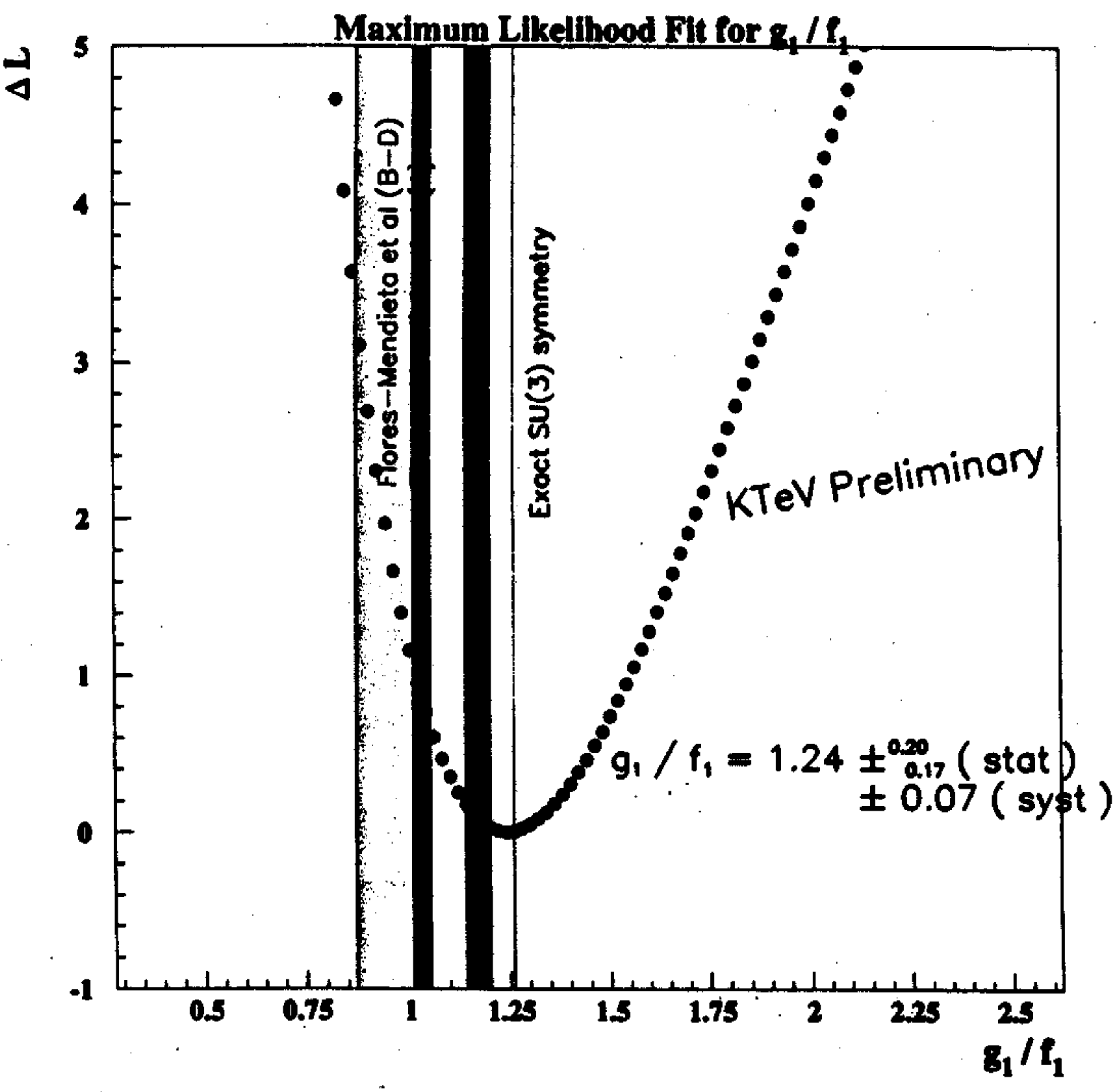
KTeV measurements:

(DPF99) $$B.R = (2.54 \pm 0.11 \pm 0.16) \times 10^{-4}$$

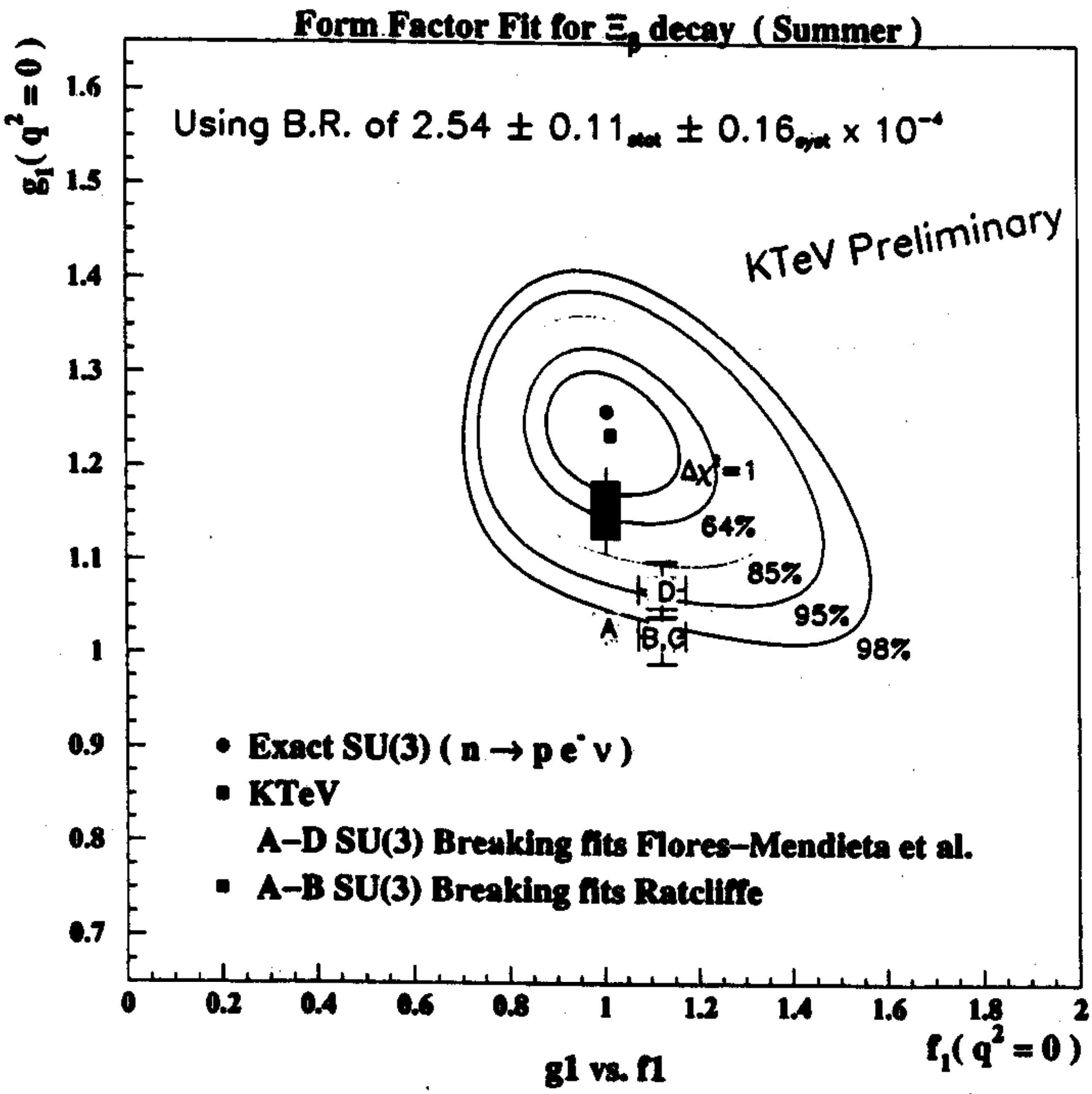
(S. Bright's talk) $$\frac{g_1}{f_1} = 1.24^{+0.20}_{-0.17} \pm 0.07$$

$$\frac{f_2}{f_1} = 1.9 \pm 1.3 \pm 0.7$$

$$\frac{g_2}{f_1} = -1.4^{+2.2}_{-1.9} \pm 0.5$$



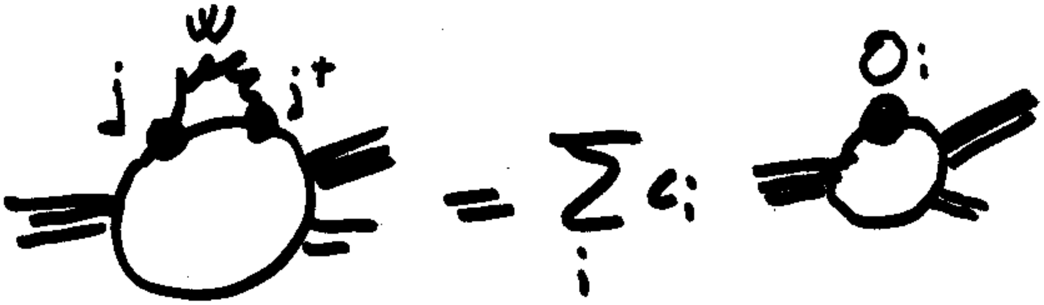
Maximum Likelihood Fit for g1 / f1
ΔL
Flores–Mendieta et al (B–D)
Exact SU(3) symmetry
KTeV Preliminary
g1 / f1 = 1.24 ±0.20 0.17 (stat)
± 0.07 (syst)
g1 / f1



▫ PRD 58·094028 (1998)

■ PRD 59·014038 (1999)

Problem with non leptonic and radiative decays.



O_i = Fermi like four quark operators.

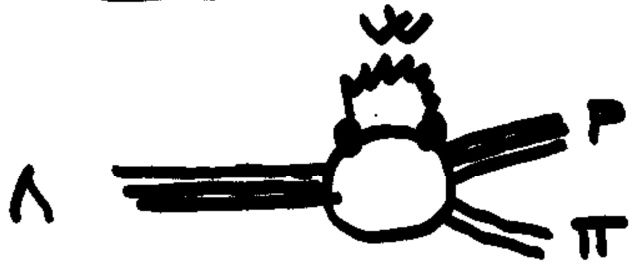
Inroads being made with Lattice simulations.

Progress is impressive for B decays, but far from credible results in Hyperon case.

<u>Models</u> vs. <u>Theory</u>

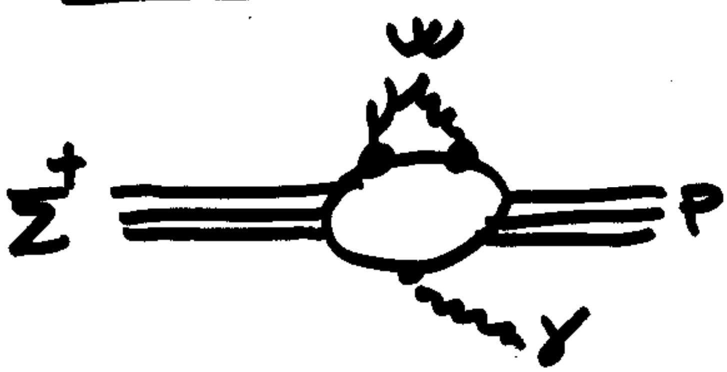
HYPERON DECAYS

Non Leptonic $\Lambda \to p\pi^- \ldots$



Hard.
CP Violation?

Radiative $\Sigma^+ \to p\gamma \ldots$



Very Hard
Hara theorem

Semi-Leptonic $\Lambda \to p e^- \bar{\nu} \ldots$

Clean
SU(3) Breaking
I-spin Breaking

ΣΛ MIXING

- When isospin is not conserved:
  $\Lambda = \Lambda_8 \cos\varphi + \Sigma_8 \sin\varphi$
  $\Sigma = -\Lambda_8 \sin\varphi + \Sigma_8 \cos\varphi$
- $\sin\varphi = -(\mathrm{sqrt}(3)/4)*(m_d - m_u)/(m_s - m_{av}) = -0.015$
- Ref: Dalitz and von Hippel(1964) MacFarlane and Sudarshan(1964) Isgur(1980), Leutwyler et al(1982)
- review: Donoghue,Ann.Rev.Nucl(1989)

EFFECTS OF MIXING ON SEMILEPTONIC DECAYS

$$R(\phi) = \Gamma(\Sigma(+) \Rightarrow \Lambda \bar{e} \nu) / \Gamma(\Sigma(-) \Rightarrow \Lambda e \bar{\nu})$$

$$= R(0)*(1 - 3.95\phi) = R(0)*(1-0.06)$$

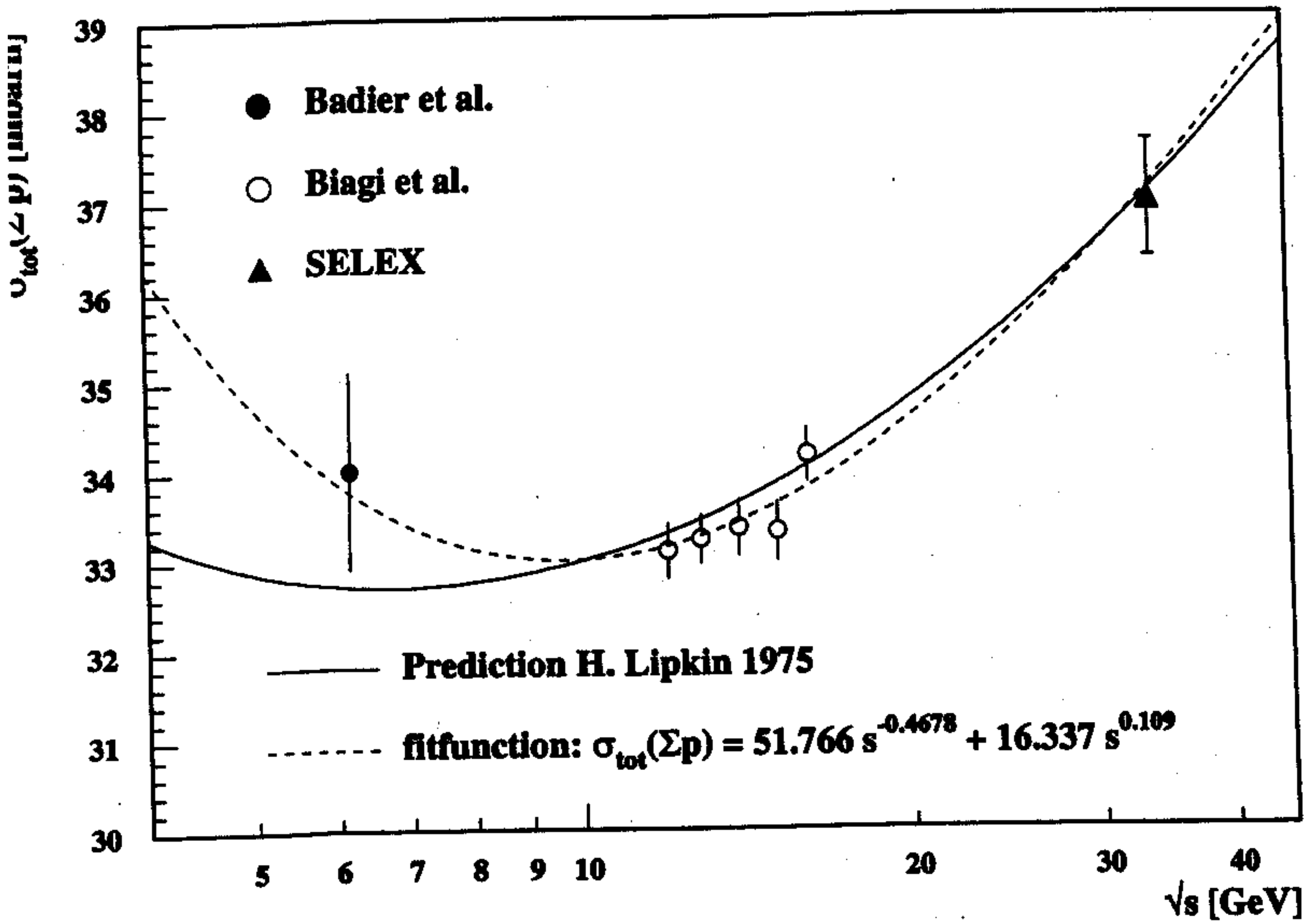
$$=0.65$$

a six percent diminution relative to no mixing. Present data is not good enough to check this value.(**Exp:R=.645+/-.18)**

Ref:Karl,Phys.Lett.B328,149(1994)
Henley&Miller,Phys.RevD50,7077(1994)

The SELEX average for $\sigma_{tot}(\Sigma^- p)$:

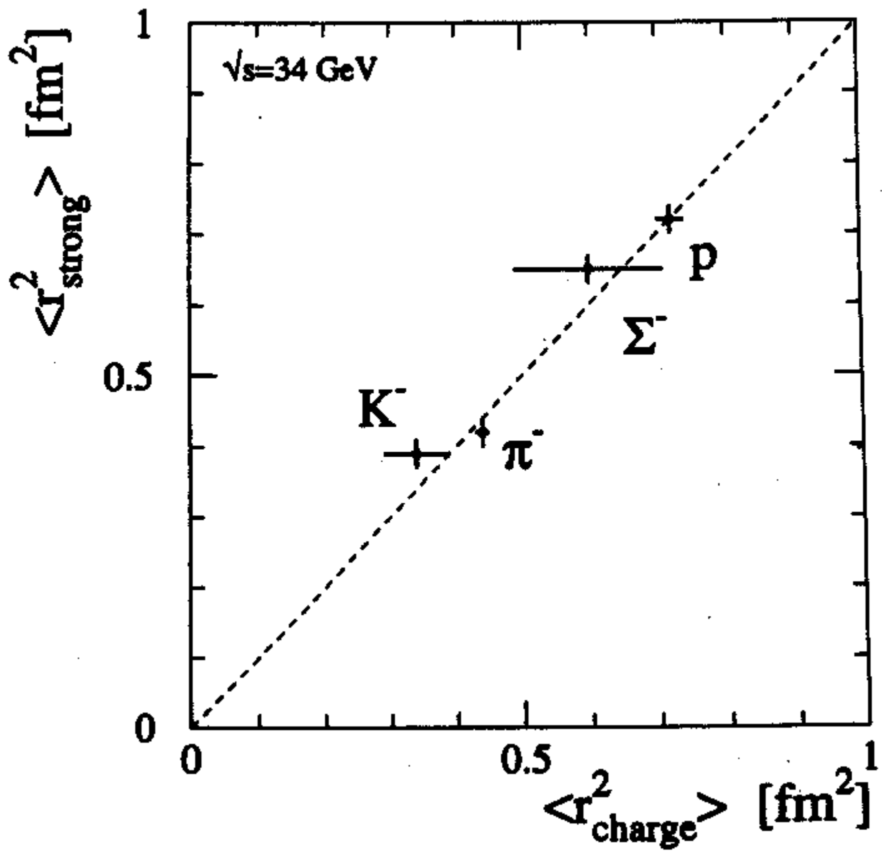
$$\sigma_{\rm tot}(\Sigma^- {\rm p}) = 36.96 \text{ mbarn} \pm 0.65 \text{ mbarn}$$
$$\text{(at 609 GeV/c)}$$



The SELEX message:

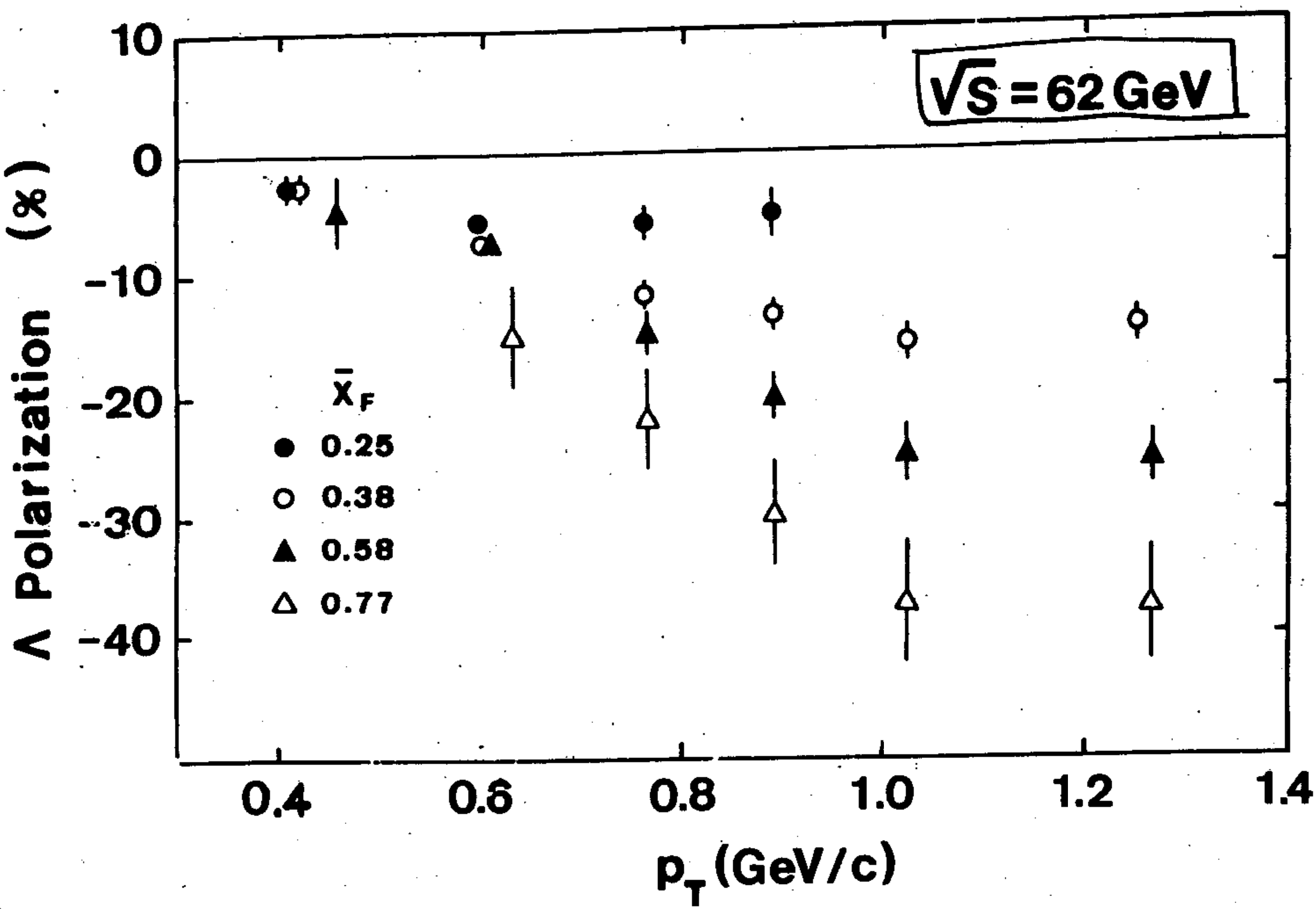
→ $\sigma_{tot}(\Sigma^- p)$ shows a definite rise with increasing center of mass energy, which is in good agreement with the TCP model of H. Lipkin.

Conclusion:
Strong and Electromagnetic Radii



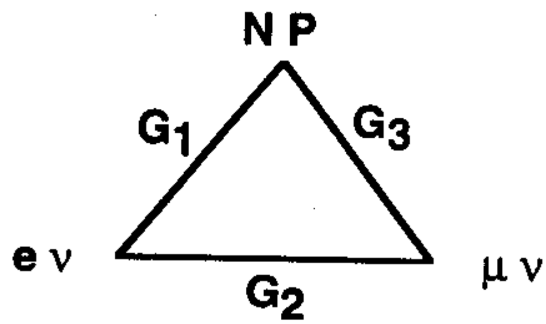
Preliminary results from E781/SELEX:

- $\sigma_{tot}(\Sigma^- N) = 37.0 \pm 0.7$ mb ($\sqrt{s} = 33.9$ GeV)
- Charge radius $\langle r^2 \rangle_{\Sigma^-} = 0.60 \pm 0.08\,\mathrm{fm}^2$



Λ Polarization (%)
10
0
-10
-20
-30
-40
$\sqrt{S}$ = 62 GeV
$\bar{x}_F$
0.25
0.38
0.58
0.77
0.4
0.6
0.8
1.0
1.2
1.4
p_T (GeV/c)

Universality of Weak Interactions 1962-63



$G_1 \approx G_2 \approx G_3$

Suggestive, but true?

$G_{\text{beta decay}} \approx 0.96\ G_{\mu\ \text{decay}}$

(Significative Difference)

And for strange particle decays....

4 - $\Lambda \rightarrow P + e + \overline{\nu}$ $\quad G_4$

$G_4 \approx 0.2\ G_{m\ \text{decay}}$

Universality and weak mixing

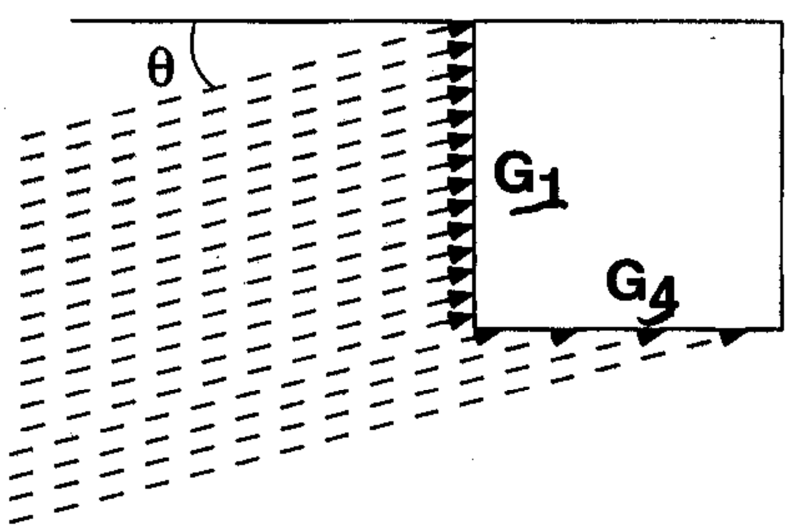
$N \to P + e^- + \nu$ $G_1 \approx 0.96\ G_{\mu\text{-decay}}$

$\Lambda \to P + e^- + \nu$ $G_4 \approx 0.2\ G_{\mu\text{-decay}}$

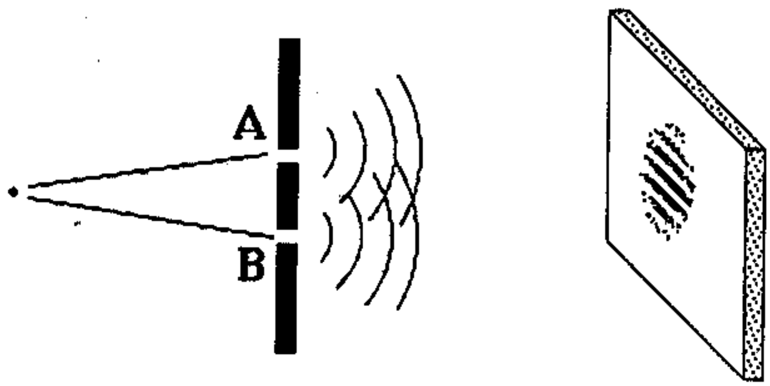
Broken Universality?
no, shared intensity

$$G_1 = \cos\theta\ G_{\mu\text{-decay}}$$
$$G_4 = \sin\theta\ G_{\mu\text{-decay}}$$

$\theta \approx$ **0.2 (today 0.221)**

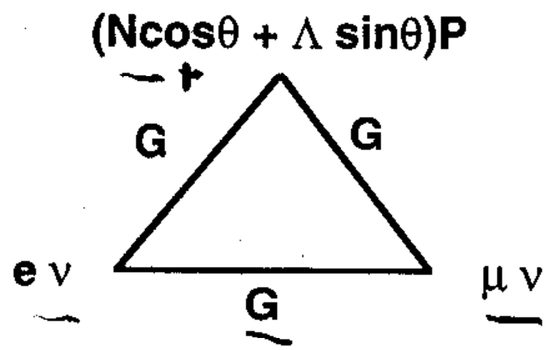


Weak Mixing
as a Quantum phenomenon



$$P_{A+B} \approx (A+B)^2$$

New Puppi Triangle



(Ncosθ + Λ sinθ) -> P + e + ν

and

μ -> e + ν + ν

have the same <u>quantum amplitude</u>

Nuovo Cimento 21 872 (1961)

2. – If one assumes that the weak currents are simply linear combinations of the currents j_m (5), one can apply (7) to derive relations between amplitudes for leptonic decays, always in the same spirit of neglecting that part of the strong Lagrangian that violates unitary simmetry. Thus, the $\Delta S=+1$, $\Delta Q=+1$ weak current could be of the form $g(j_4+ij_5)$ where g is a constant. One then has the decomposition

$$g\langle A|j_4+ij_5|B\rangle=(if_{AB4}-f_{AB5})\,\mathcal{O}'+(d_{AB4}+id_{AB5})\,\mathcal{E}', \tag{10}$$

where $\mathcal{O}'$ and $\mathcal{E}'$ are $g\mathcal{O}$ and $g\mathcal{E}$.

If one assumes universality in the coupling of the weak currents to the leptons the $\Delta S=0$, $\Delta Q=+1$ weak current would be $g(j_1+ij_2)$, with the same g as in (10). But then the rates for hyperon leptonic decays would be much larger than observed. Therefore the use of the universality hypothesis is, at least, inconvenient, in such a scheme; of course, the hypothesis may be true, but masked by strong renormalization effects. We do not therefore insist on the relations between matrix elements of different currents. From (10) one finds

$$\left\{\begin{aligned}
g\langle\Xi^-|j_4+ij_5|\Lambda\rangle &= \frac{1}{\sqrt{2}}\left(\sqrt{3}\,\mathcal{O}'-\frac{1}{\sqrt{3}}\,\mathcal{E}'\right),\\
g\langle\Sigma^-|j_4+ij_5|n\rangle &= -\mathcal{O}'+\mathcal{E}',\\
g\langle\Sigma^0|j_4+ij_5|p\rangle &= \frac{1}{\sqrt{2}}\,(-\mathcal{O}'+\mathcal{E}'),\\
g\langle\Lambda|j_4+ij_5|p\rangle &= \frac{1}{\sqrt{2}}\left(-\sqrt{3}\,\mathcal{O}'-\frac{1}{\sqrt{3}}\,\mathcal{E}'\right),\\
g\langle\Xi^-|j_4+ij_5|\Sigma^0\rangle &= \frac{1}{\sqrt{2}}\,(\mathcal{O}'+\mathcal{E}'),\\
g\langle\Xi^0|j_4+ij_5|\Sigma^+\rangle &= \mathcal{O}'+\mathcal{E}'.
\end{aligned}\right. \tag{11}$$

3. – Still in the same spirit of neglecting violations of unitary simmetry we can easily establish that, in the limit of zero momentum transfer, $\mathcal{E}'\to 0$ (*i.e.* the form factor multiplying γ_μ in the expansion of $\mathcal{E}'$ is zero for $K^2=0$). In fact in the limit of zero momentum transfer the relevant matrix element is proportional to $\langle A|F_4+iF_5|B\rangle$, since the generators F_m are also the space integrals of the fourth component of j_m (and, of course, are conserved if j_m is divergenceless). However

1) $\frac{K\to\mu\nu}{\pi\to\mu\nu} = \frac{K\to\pi e\nu}{\pi\to\pi e\nu} \Rightarrow \theta \approx 0.26$

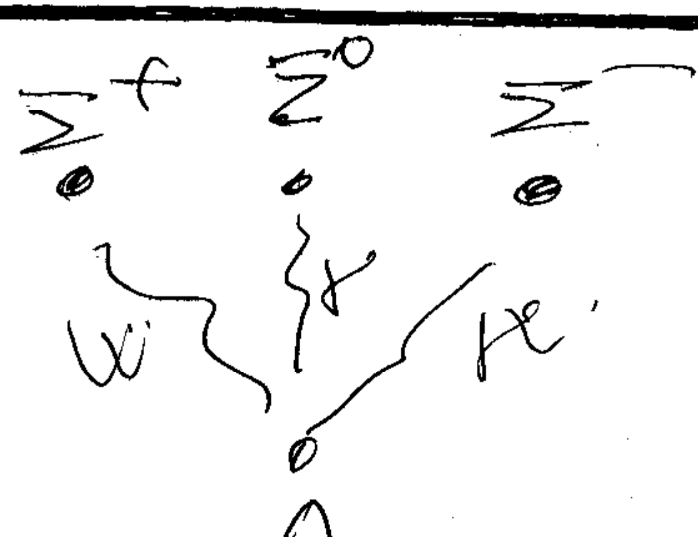
[Maint. $\theta = 0.2196 \pm 0.0023$]

2) use as input $\begin{cases} n\to p e^-\bar{\nu} \\ \Sigma^\pm \to \Lambda e \nu \end{cases}$

and predict ⇓

Table I. Predictions for the leptonic decays of hyperons.

Decay	Branching ratio From reference 2	Branching ratio Present work	Type of interaction
$\Lambda\to p+e^-+\bar{\nu}$	1.4 %	0.75×10^{-3}	$V-0.72A$
$\Sigma^-\to n+e^-+\bar{\nu}$	5.1 %	1.9×10^{-3}	$V+0.65A$
$\Xi^-\to\Lambda+e^-+\bar{\nu}$	1.4 %	0.35×10^{-3}	$V+0.02A$
$\Xi^-\to\Sigma^0+e^-+\bar{\nu}$	0.14 %	0.07×10^{-3}	$V-1.25A$
$\Xi^0\to\Sigma^++e^-+\bar{\nu}$	0.28 %	0.26×10^{-3}	$V-1.25A$



What does it mean

in Standard Model:

$$\mathcal{L}_H = \bar{u}_L M_u u_R + \bar{d}_L M_d d_R + \dots$$

> from Higgs Fields

$$J^\mu = \bar{u}_L \gamma^\mu d_L$$

→ Diagonalize Mass Matrices:

$$M_u = L_u^\dagger D_u R_u \,, \quad M_d = L_d^\dagger D_d R_d$$

→ $$D_u = \begin{pmatrix} m_u & & \\ & m_c & \\ & & m_t \end{pmatrix} \dots$$

→ Define rotated fields:

$$u'_R = R_u u_R \,, \quad d'_R = R_d d_R$$

$$u'_L = L_u u_L \,, \quad d'_L = L_d d_L$$

Then we obtain:

$$\mathcal{L}_H = \bar{u}'_L D_u u'_R + \bar{d}'_L D_d d'_R$$

$$J^\mu = \bar{u}'_L \gamma^\mu V d_L$$

$$\boxed{V = L_u L_d^\dagger}$$

→ One would like to infer M_u, M_d from V, D_u, D_d – (experimental)

This is not directly possible.

→ But one can use ~~specific~~ V, D_u, D_d to test specific hypothesis.

→ CP violation is inscribed in the M_u, M_d matrices.

The Jarlskog relation:

$$\det\left[M_u^2, M_d^2\right] \propto$$

$$i\,(m_t^2 - m_c^2)(m_c^2 - m_u^2)(m_t^2 - m_u^2)$$
$$\times (m_b^2 - m_s^2)(m_b^2 - m_d^2)(m_s^2 - m_d^2)$$
$$\times (\text{Area of unitarity triangle})$$

<u>But</u> M_d, M_u
come from Higgs coupling.

⇒ Higgs coupling breaks
CP symmetry.

⇒ Is it spontaneous
breaking?

If so, it must happen
close to the Planck scale,
or at the scale of SUSY
breaking (or technicolor
breaking, or....)

A message from
far away.

Hyperons – the future

(My very personal selection)

1) Hyperon beta decay
   - improved across the board
   - but especially
     $\Sigma^{\pm} \rightarrow \Lambda e \nu$
     → Test of CVC
     → I-spin breaking

2) CP violation in Hyperon non leptonics

3) $\pi^+ \rightarrow \pi^0 e^+ \nu$ at 1 ppm.
   Independent determination of V_{ud}.
   ... not an hyperon...

4) Lattice QCD and SU(3) breaking in Hyperon beta decay.