Recent Results from *BNL E865*

Alexander Sher
University of Pittsburgh

Workshop on Heavy Quarks at Fixed Target
At Fermi National Laboratory
October 10-12, 1998

Experiment E865 at the BNL AGS is a search for the Lepton Family violating decay $K^+ \to \pi^+\mu^+e^-$. We aim to reach a sensitivity in the $\sim 1 \cdot 10^{-11}$ range for this decay.
E865 apparatus allows to collect and study other rare and semi rare K^+ decays.
Results will be shown on
$K^+ \to \pi^+\mu^+e^-$, $K^+ \to \pi^+e^+e^-$, $K^+ \to \pi^+\mu^+\mu^-$,
$K^+ \to \pi^+\pi^-e^+\nu$, $K^+ \to e^+\nu e^+e^-$, $K^+ \to \mu^+\nu e^+e^-$,
$K^+ \to \pi^0e^+\nu$ ($\pi^0 \to e^+e^-\gamma$).

The E865 Collaboration

H. Ma, D.M. Lazarus, L. Leipuner, P. Rehak
Brookhaven National Laboratory

G.S. Atoyan, V.V. Isakov, A.A. Poblaguev,
A.L. Proskurjakov
Institute for Nuclear Research, Moscow

B. Bassalleck, S. Eilerts, H. Fischer, J. Lowe, R. Stotzer
University of New Mexico

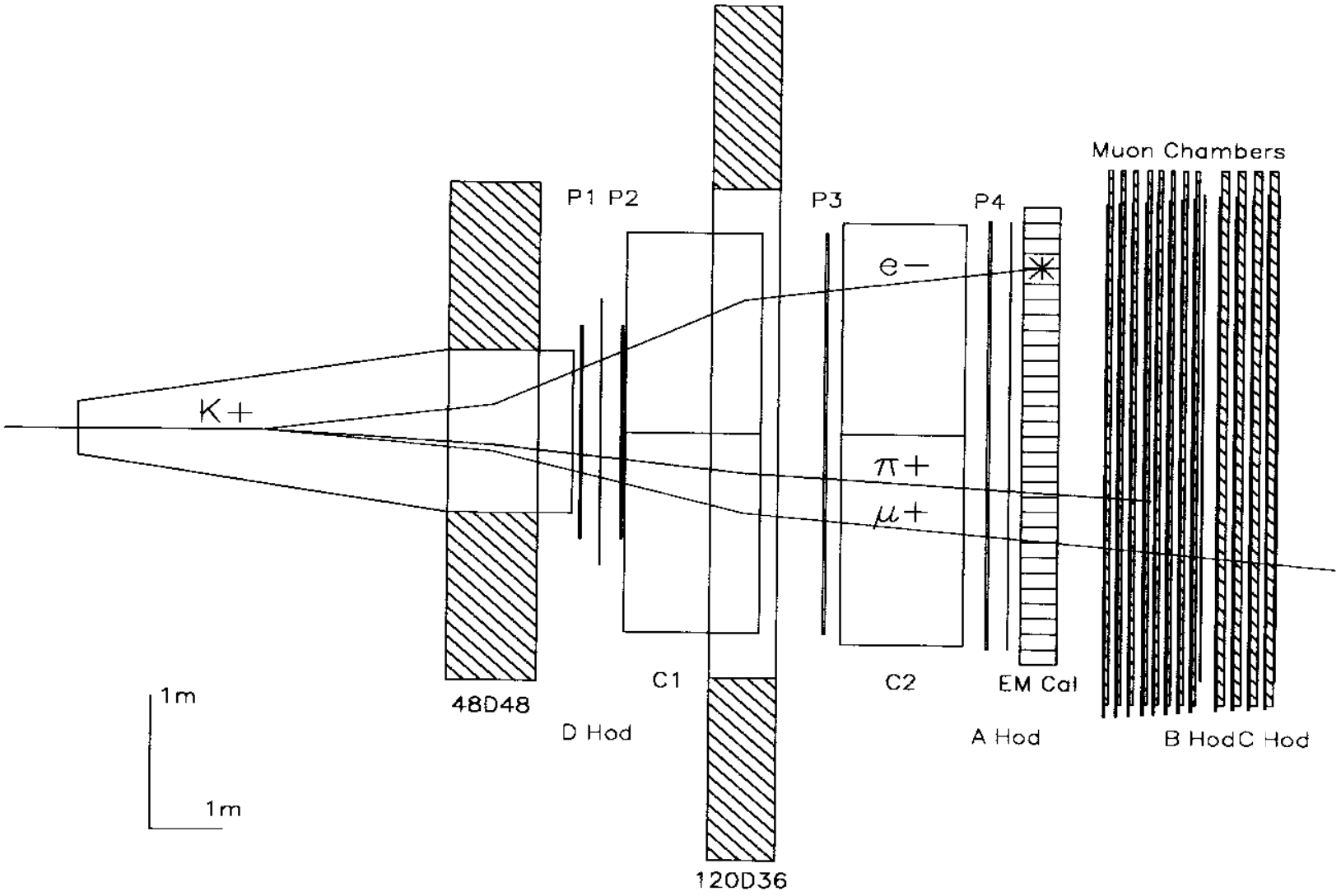
J. Egger, W. Herold, H. Kaspar
Paul Scherrer Institute

W. Menzel, H. Weyer
University of Basel

R. Appel, D.N. Brown, N. Cheung, C. Felder, M. Gach,
D.E. Kraus, A. Sher, J.A. Thompson
University of Pittsburgh

D. Bergman, S. Dhawan, H. Do, J. Lozano, W. Majid,
M.E. Zeller
Yale University

S. Pislak, P. Robmann, P. Truoel
University of Zurich


E865, Plan Diagram, K+ → π+μ+e−
Muon Chambers
P1 P2
P3
P4
e−
K+
π+
μ+
1m
1m
48D48
D Hod
C1
C2
EM Cal
A Hod
B Hod
C Hod
120D36

Processes observed by E865.

Process	BR (PDG)	# of previously observed events	# of events observed by E865	Why Study?
$K^+ \to \pi^+\mu^+e^-$	$< 2.1\cdot10^{-10}$ (90%CL)			
$K^+ \to \pi^+e^+e^-$	$(2.74 \pm 0.23)\cdot10^{-7}$	1,341	~10,000	**ChPT**
$K^+ \to \pi^+\mu^+\mu^-$	$(5.0 \pm 1.0)\cdot10^{-8}$	203	~400	**ChPT**
$K^+ \to \pi^+\pi^-e^+\nu$	$(3.91\pm0.17)\cdot10^{-5}$	~30,000	~300,000	**ChPT and $\pi\pi$ scattering**
$K^+ \to e^+\nu e^+e^-$	$(3+3-1.5)\cdot10^{-8}$	4	~380	**ChPT**
$K^+ \to \mu^+\nu e^+e^-$	$(1.3\pm0.4)\cdot10^{-7}$	14	~1500	**ChPT**
$K^+ \to \pi^0e^+\nu$ *	$(4.82\pm0.06)\cdot10^{-2}$	~4,000$^+$	~60,000	**Vus and form-factors study**
$K^+ \to \pi^0\mu^+\nu$ *	$(3.18\pm0.08)\cdot10^{-2}$	~4,000$^+$	~60,000	**Form factors study.**
$K^+ \to \pi^+\pi^+\pi^-$	$(5.59\pm0.05)\cdot10^{-2}$			**Normalization and Detector Calibration**
$K^+ \to \pi^+\pi^0$ *	$(21.16\pm0.14)\cdot10^{-2}$			**Normalization and Detector Calibration**

* In these processes π^0 is detected through $\pi^0 \to e^+e^-\gamma$ (BR=$(1.198\pm0.032)\cdot10^{-2}$).

$^+$ Maximum number of events in the single experiment where branching ratio was obtained

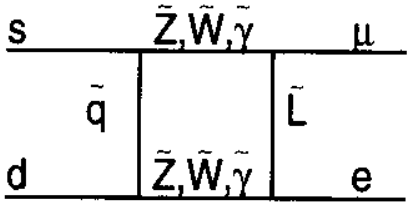
We can study form factors in all rare and semi rare kaon decays listed above.

$K^+ \to \pi^+ \mu^+ e^-$

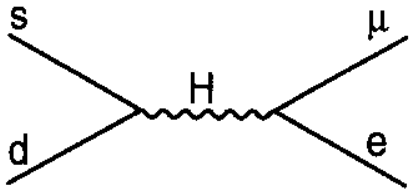
Search "beyond the Standard Model"

Some Extensions to the Standard Model which allow Lepton Flavor Violation:

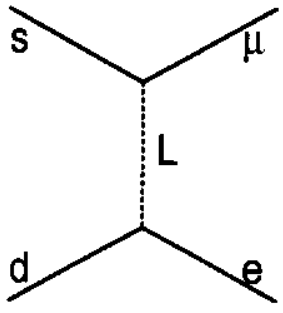
1. Supersymmetry



2. Extended Technicolor

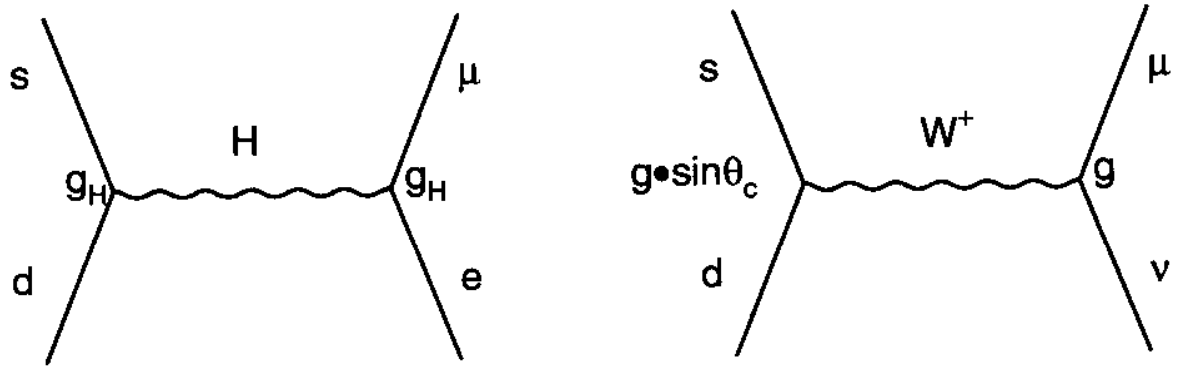


3. Leptoquarks



$K^+ \to \pi^+ \mu^+ e^-$

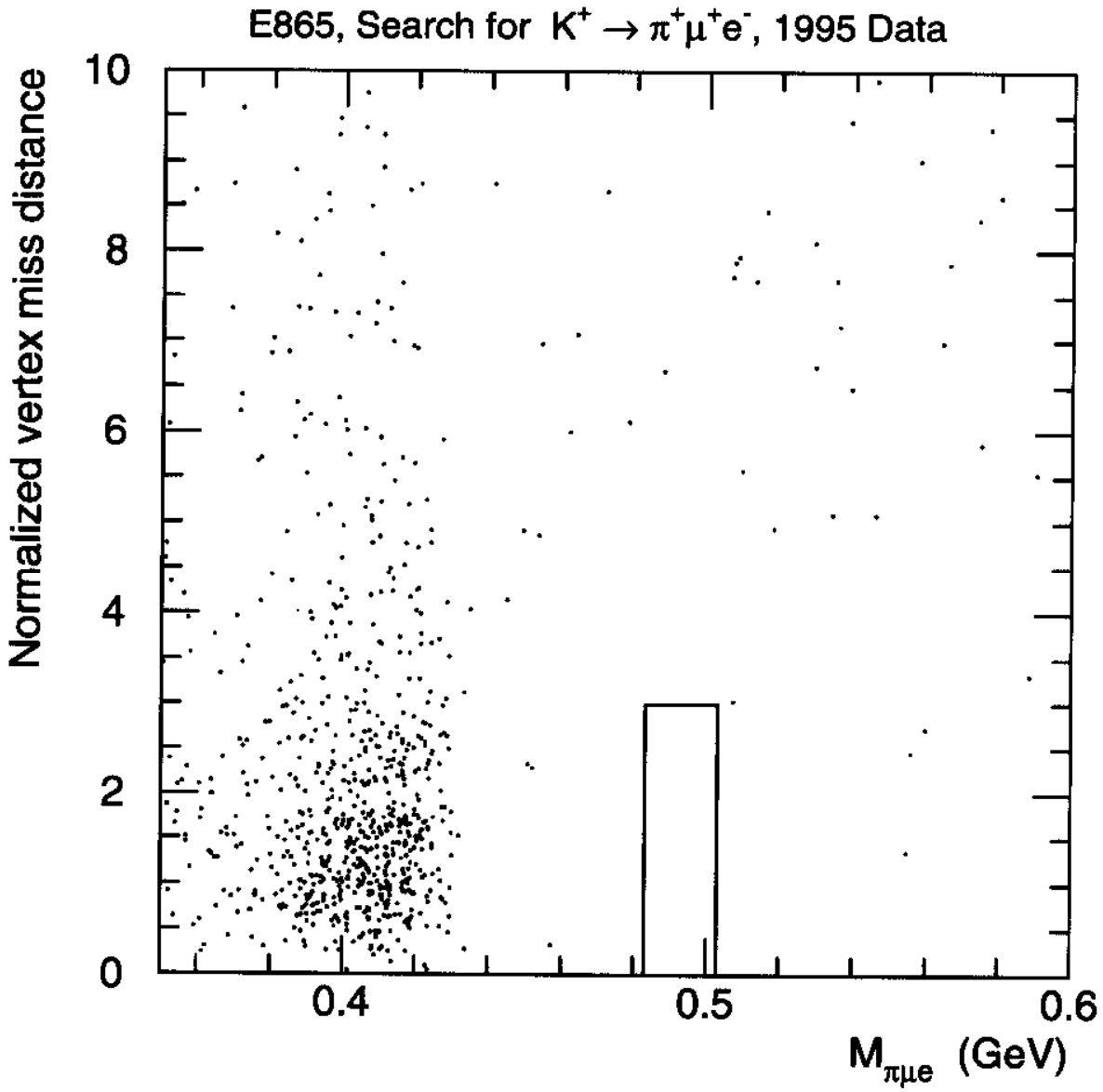
Model Independent Effective Lagrangian Compared to $K^+ \to \pi^0 \mu^+ \nu$



$$\frac{\Gamma(K^+ \to \pi^+ \mu^+ e^-)}{\Gamma(K^+ \to \pi^0 \mu^+ \nu)} \propto \frac{1}{\sin^2\theta_c} \cdot \left(\frac{g_H}{g}\right)^4 \cdot \left(\frac{M_W}{M_H}\right)^4 \Rightarrow$$

$$\Rightarrow \frac{g}{g_H} \cdot M_H = \left[\frac{M_W^4}{\sin^2\theta_c} \cdot \frac{BR(K^+ \to \pi^0 \mu^+ \nu)}{BR(K^+ \to \pi^+ \mu^+ e^+)}\right]^{1/4}$$

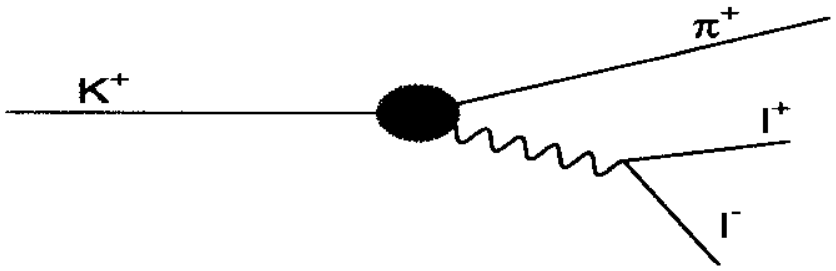
Current Limit on $BR(K^+ \to \pi^+ \mu^+ e^-)$ is $2.1 \cdot 10^{-10}$ (90% CL).
This corresponds to $M_H > 18$TeV.

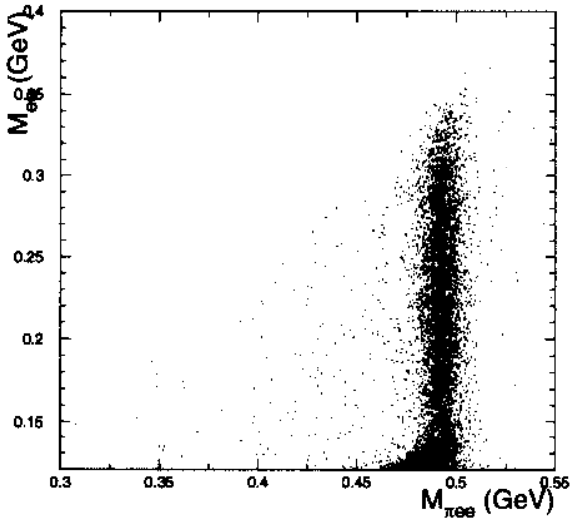


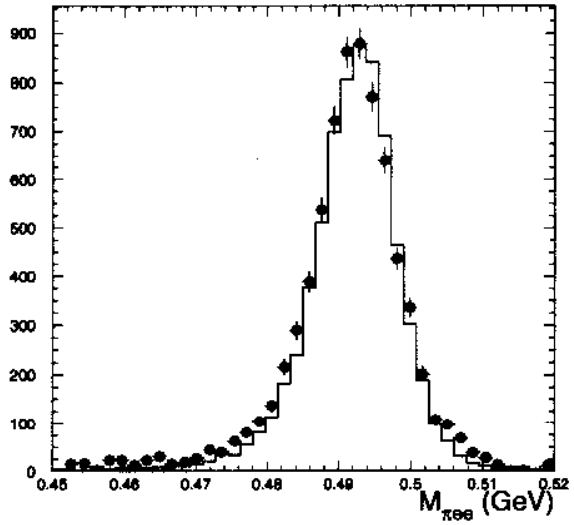
1995 E865 Data yields BR($K^+ \to \pi^+\mu^+e^-$) < $2.1 \cdot 10^{-10}$(90% CL)
Combined with 1996 Data (is processed now) and 1998 Data (run is in process now) we aim to reach ~$1 \cdot 10^{-11}$ sensitivity to this decay.
This corresponds to M_H>40TeV.

$K^+ \rightarrow \pi^+ e^+ e^-$

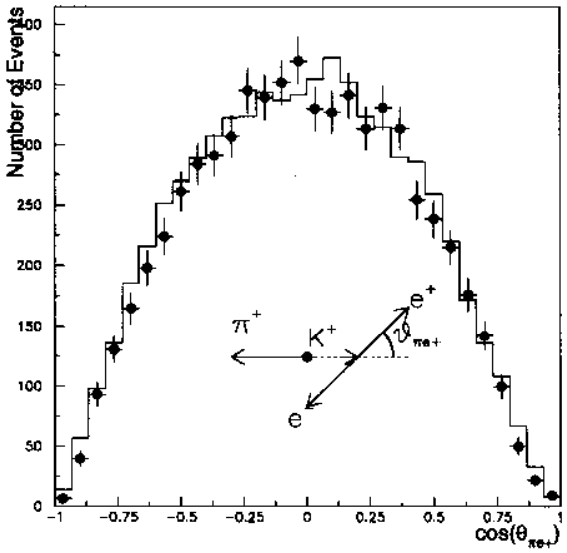
~10K events



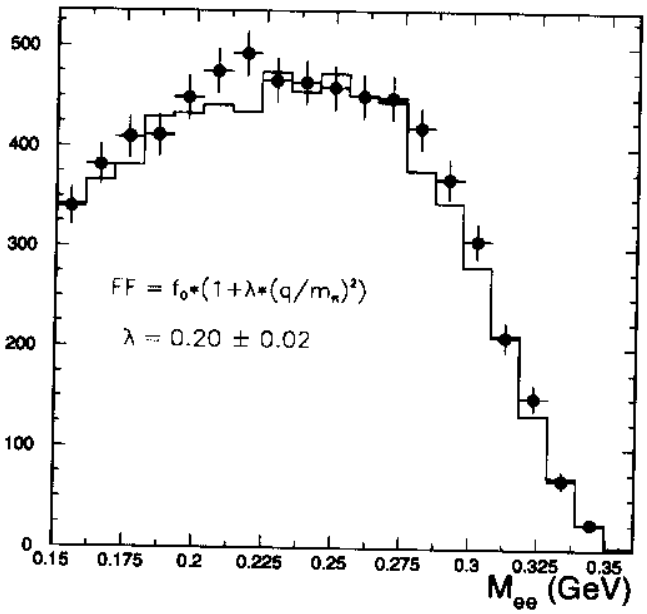


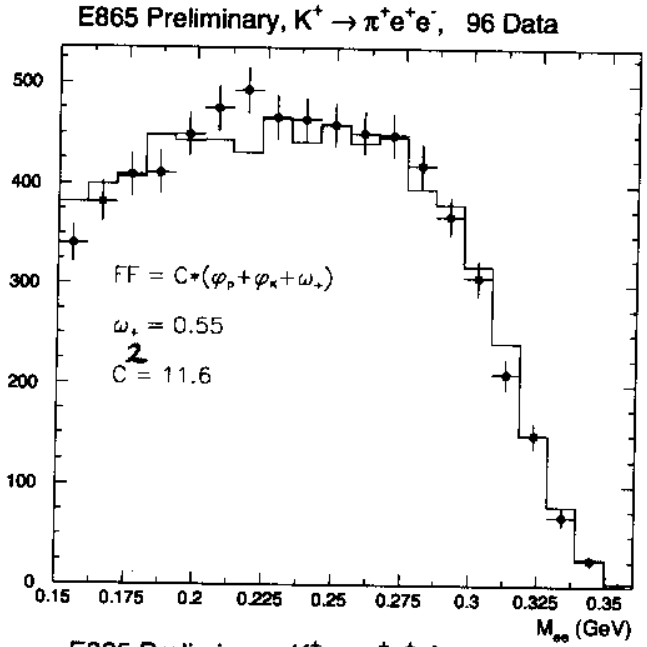


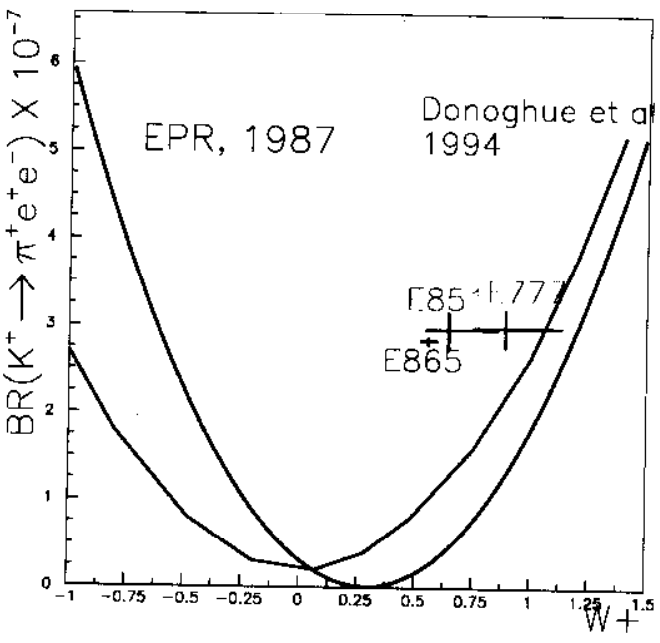
M_{ee} > 150MeV
Compared to MC.

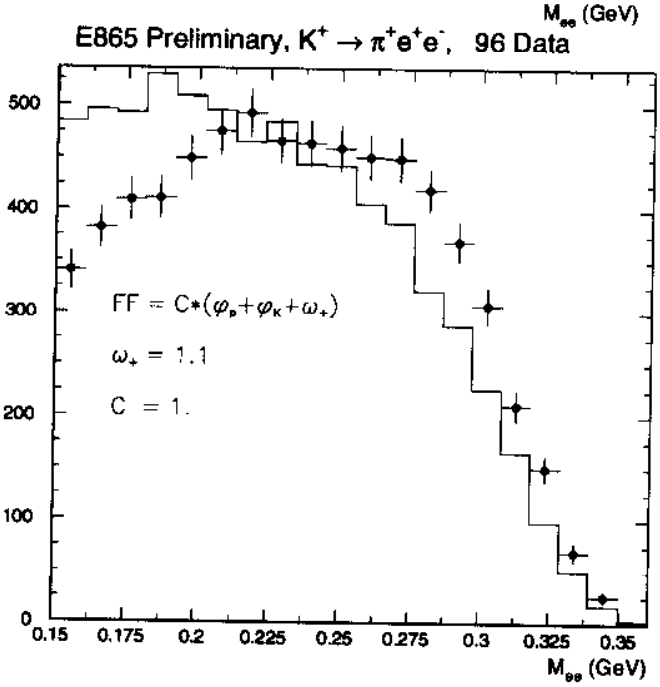


<- cosθ distribution in comparison with MC simulation with pure vector interaction.









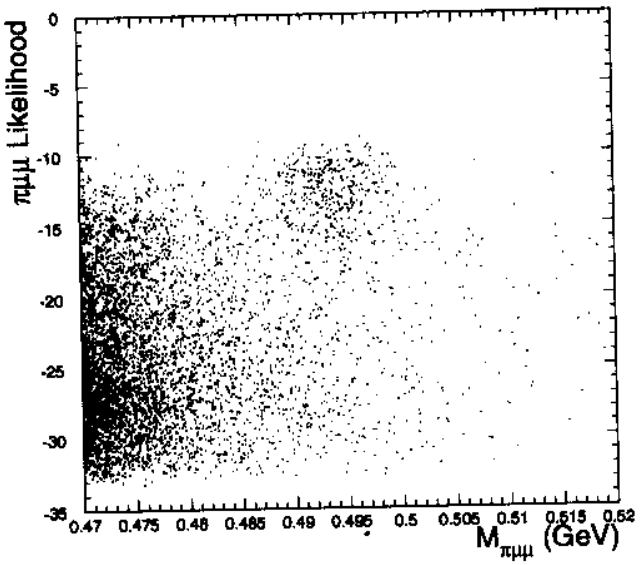
$$\frac{d\Gamma}{dM_{ee}} \propto M_{ee} \cdot P_\pi^3 \left(1+\lambda\left(\frac{M_{ee}}{M_\pi}\right)^2\right)^2 \quad \text{OR} \quad \frac{d\Gamma}{dM_{ee}} = 16 \cdot M_{ee} \cdot \bar{\Gamma} \cdot P_\pi^3 \cdot \frac{|\Phi_+|^2}{M_k^5}$$

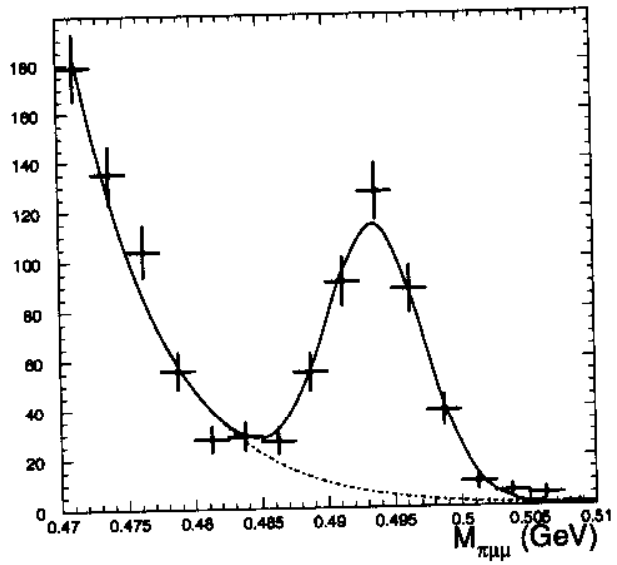
$$BR=(2.7+/-0.2)\cdot 10^{-7}$$

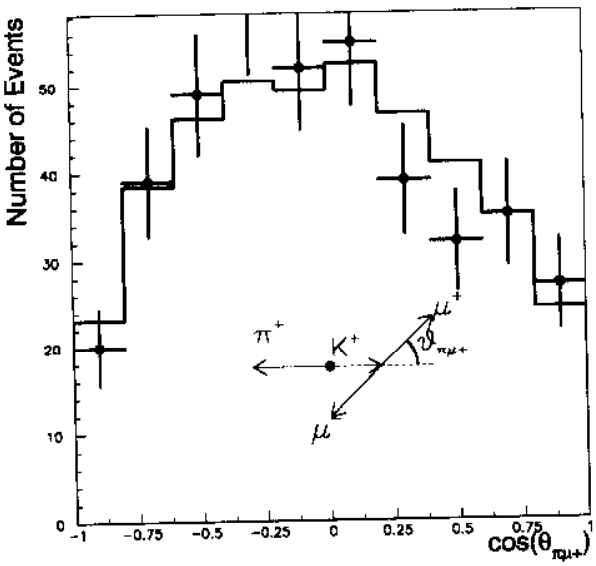
ChPT of $O(p^4)$ is insufficient to describe $K^+ \to \pi^+e^+e^-$ data.

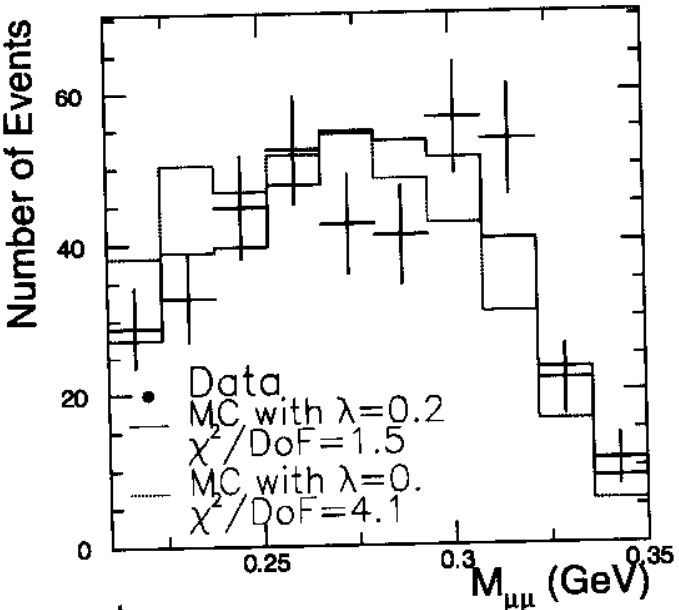
$K^+ \rightarrow \pi^+\mu^+\mu^-$

Main background: $K^+ \rightarrow \pi^+\pi^+\pi^-$ ($\pi^{+/-} \rightarrow \mu^{+/-}\nu$).









Observe ~400 events.

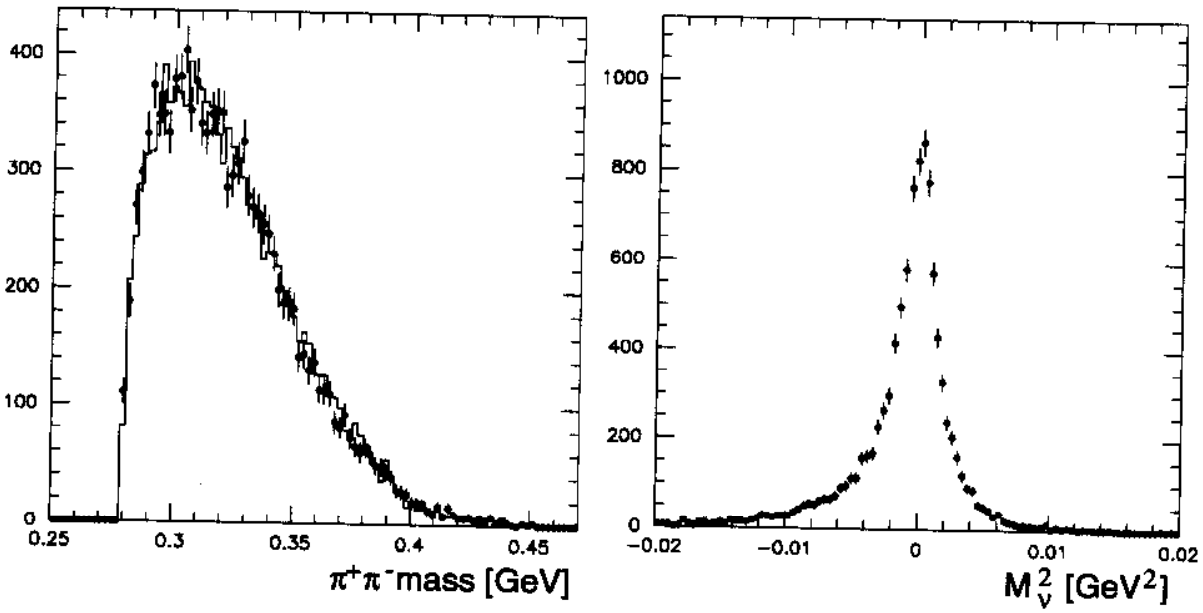
Angular Distribution is consistent with pure vector interaction.

Form factor Fit is consistent with $K^+ \rightarrow \pi^+e^+e^-$.

Work is in progress on obtaining Branching Ratio.

K_{e4} decay: $K^+ \to \pi^+\pi^-e^+\nu$

- Physics:
  - Cleanest mean to study the $\pi\pi$ interaction at low energies.
  - Form factors.
  - Test of Chiral Perturbation Theory.
- E865 collected 300,000 events, 10 times the current total data, with a good phase space coverage.
- Background $< 2\%$, mainly from $K^+ \to \pi^+\pi^+\pi^-$.



$\pi^+\pi^-$ mass for reconstructed Monte Carlo (histogram) and data (marker) K_{e4} events, and missing neutrino mass squared. These plots comprise about 4% of our data.

A first glimpse

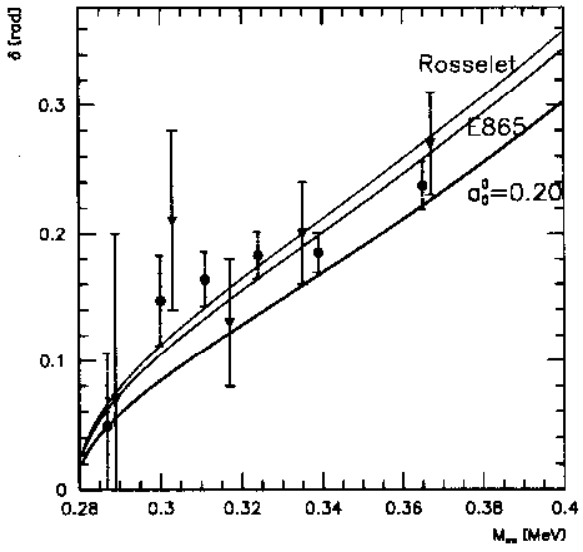
VERY, VERY PRELIMINARY

- Use about half of our data, i.e. 150k events
- Acceptance of detector calculated based on only 240k events.

$M_{\pi\pi}$ (MeV)	280-294	294-305	305-317	317-331	331-350	> 350
$< M_{\pi\pi} >$ (MeV)	287	300	311	324	339	367
g	0.42	0.46	0.51	0.48	0.80	0.52
g'	0.60	0.71	0.68	0.66	0.76	0.73
h	-0.50	-0.27	-0.27	-0.79	-0.20	-0.16
δ (rad)	0.049	0.147	0.164	0.185	0.185	0.238
χ^2/NdF	2.0	1.9	1.9	2.0	1.9	1.8

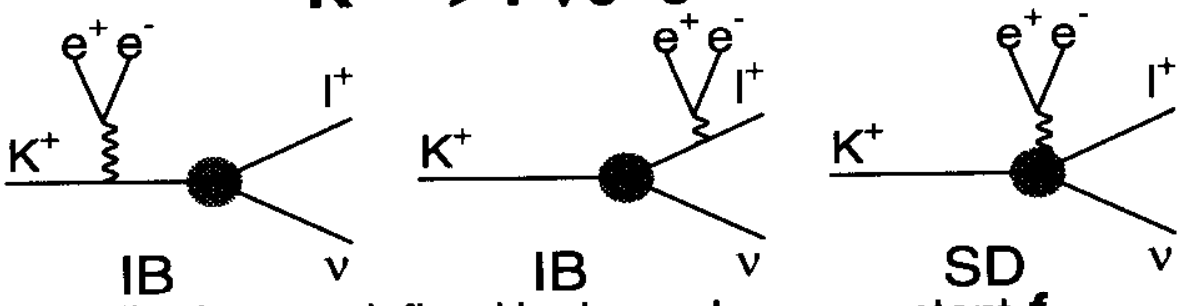
δ allows to calculate the scattering length a_o^o. Following the model of Basdevant *et al.* (NP B72, 413 (1974)), there is:

$$\sin(2\delta) = 2\sqrt{\frac{s_\pi - 4M_\pi^2}{s_\pi}} \cdot \left(a_o^o + (0.19 - (a_o^o - 0.15)) \sqrt{\frac{s_\pi - 4M_\pi^2}{4M_\pi^2}} \right)$$



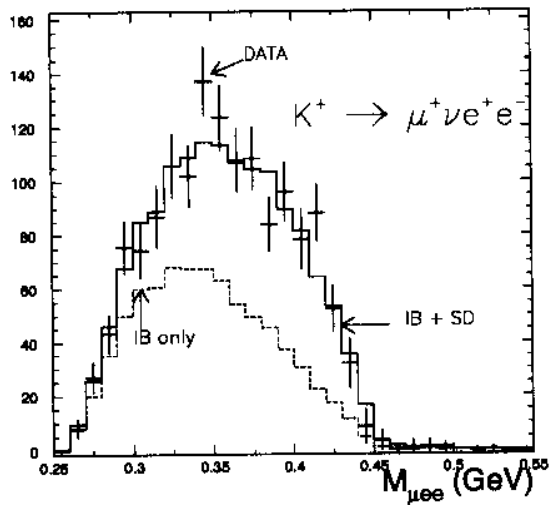
Only statistical errors for E865!!!

$K^+ \rightarrow l^+ \nu e^+ e^-$

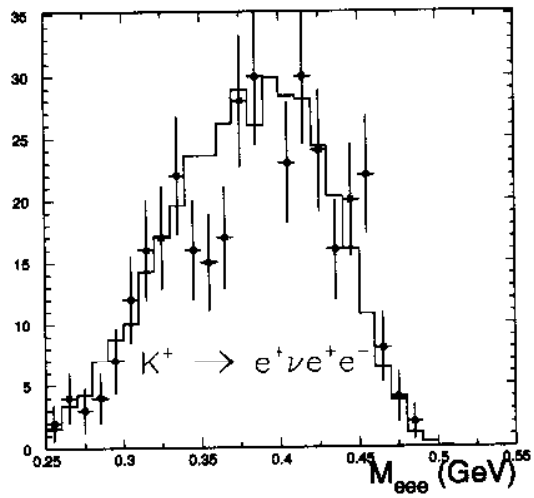


IB Amplitudes are defined by kaon decay constant f_K

SD amplitude is parameterized by form factors F_V, F_A, and R



~1500 events



~380 events

Left: μee mass distribution in comparison with MC with only IB part and IB+SD parts.

Right: eee mass distribution in $K^+ \rightarrow e^+\nu e^+e^-$ in comparison with MC which is dominated by SD part

Measurement of structure dependent part of the Decay.

First measurement of electromagnetic form factor R in K^+ decays.

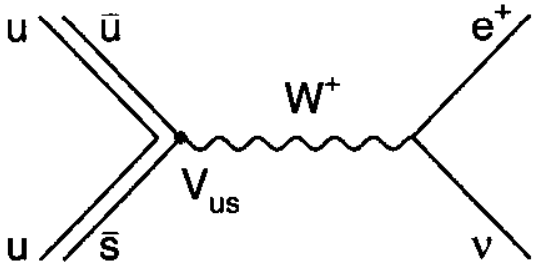
Improved measurement of Vector and Axial form factors F_V and F_A.

Branching ratio measurement.

Work in progress.

$K^+ \rightarrow \pi^0 e^+ \nu$

~ 60,000 events



Unitarity Sum: $|V_{ud}|^2 + |V_{us}|^2 + |V_{ub}|^2 = 0.9968 \pm 0.0014$

$|V_{ud}| = 0.9740 \pm 0.0014$

$|V_{us}| = 0.2196 \pm 0.0023$ (only from K_{e3})*

$|V_{ub}| = 0.0032 \pm 0.0008$

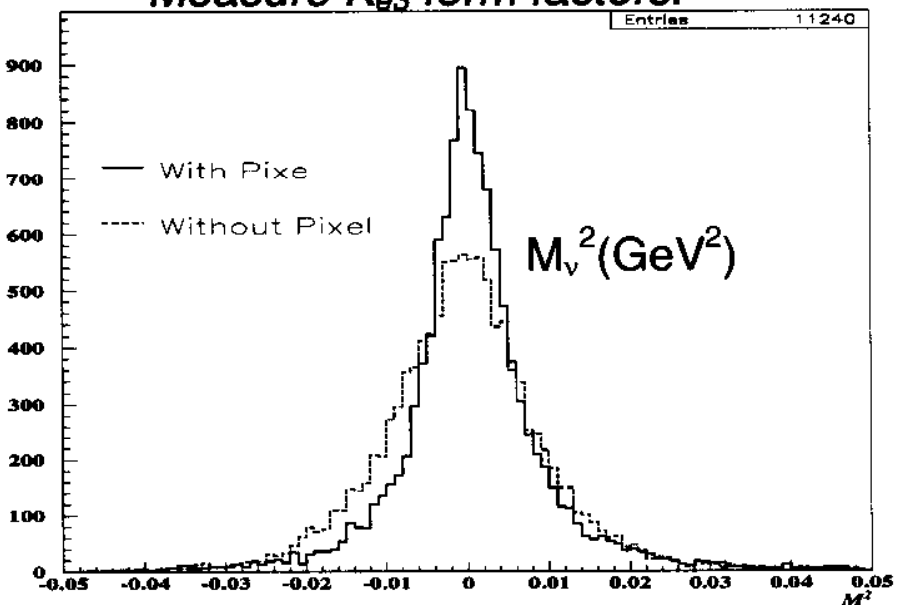
$$d\Gamma\left(K^+ \rightarrow \pi^0 e^+ \nu\right) \propto |V_{us}|^2 \cdot |f_+(0)|^2 \cdot \left[1 + \lambda_+ \left(q^2 / m_\pi^2\right)\right]^2 dq^2$$

Goal: *Measure BR($K^+ \rightarrow \pi^0 e^+ \nu$)*

via $\dfrac{BR(K^+ \rightarrow \pi^0 e^+ \nu; \pi^0 \rightarrow e^+ e^- \gamma)}{BR(K^+ \rightarrow \pi^0 \pi^+; \pi^0 \rightarrow e^+ e^- \gamma)}$ (to 1%)

(PDG: BR($K^+ \rightarrow \pi^0 \pi^+$)=(21.16+/-0.14)%)

Measure K_{e3} form factors.



Work in progress.

* K_{e3} based calculation represents less theoretical error than calculation based on Hyperon decays.

Conclusion

$K^+ \to \pi^+\mu^+e^-$	1995: BR<$2.1\cdot10^{-10}$ (90% CL) +1996+1998 data: expect to reach ~$1\cdot10^{-11}$ sensitivity, which corresponds to M_H~40TeV.
$K^+ \to \pi^+e^+e^-$	observe ~10,000 events. BR=$(2.7+/-0.2)\cdot10^{-7}$ λ=0.20+/-0.02 Data confirms vector interaction. Data can not be described by ChPT of $O(p^4)$
$K^+ \to \pi^+\mu^+\mu^-$	observe ~ 400 events. Data confirms vector interaction. λ measurement is consistent with $K^+ \to \pi^+e^+e^-$. Work is in progress on obtaining form factors and branching ratio.
$K^+ \to \pi^+\pi^-e^+\nu$	observe ~300,000events. Cleanest way to study low energy $\pi\pi$ interactions. Work in progress on obtaining scattering parameters, form factors and branching ratio.
$K^+ \to e^+\nu e^+e^-$	observe ~380 events. Work in progress on obtaining form factors describing Structure Dependant part of the Amplitude and Branching ratio.
$K^+ \to \mu^+\nu e^+e^-$	observe ~1500 events. Work in progress on obtaining form factors describing Structure Dependant part of the Amplitude and Branching ratio.
$K^+ \to \pi^0e^+\nu$ ($\pi^0 \to e^+e^-\gamma$)	observe ~60,000 events. Work in progress on obtaining precision (up to 1%) branching ratio and form factors.
$K^+ \to \pi^+e^+e^-\gamma$	see about 30 events. Work in progress. No theoretical prediction available.
$K^+ \to \pi^+\pi^0e^+e^-$	see about 30 events. Work in progress. No theoretical prediction available.