One question that we cannot skip:

\[ K \rightarrow \pi \nu \nu \]

Based on the talks given at the Flavor Physics session of the Alghero Dafne2 Workshop

Fernando Ferroni
Roma “La Sapienza”
& INFN Roma

Try to stick to facts
The wildest dream

<table>
<thead>
<tr>
<th></th>
<th>b $\rightarrow$ s</th>
<th>b $\rightarrow$ d</th>
<th>s $\rightarrow$ d</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>$\Delta F=2$ box</strong></td>
<td>$\Delta M_{B_s}$, $A_{CP}(B_s \rightarrow \psi \phi)$</td>
<td>$\Delta M_{B_d}$, $A_{CP}(B_d \rightarrow \psi K)$</td>
<td>$\Delta M_K$, $\varepsilon_K$</td>
</tr>
<tr>
<td><strong>$\Delta F=1$ 4-quark box</strong></td>
<td>$B_d \rightarrow \phi K$, $B_d \rightarrow K\pi$, ...</td>
<td>$B_d \rightarrow \pi \pi$, $B_d \rightarrow \rho \pi$, ...</td>
<td>$\varepsilon'/\varepsilon$, $K \rightarrow 3\pi$, ...</td>
</tr>
<tr>
<td><strong>gluon penguin</strong></td>
<td>$B_d \rightarrow X_s \gamma$, $B_d \rightarrow \phi K$, $B_d \rightarrow K\pi$, ...</td>
<td>$B_d \rightarrow X_d \gamma$, $B_d \rightarrow \pi \pi$, ...</td>
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</tr>
<tr>
<td><strong>$\gamma$ penguin</strong></td>
<td>$B_d \rightarrow X_s \ell^+ \ell^-$, $B_d \rightarrow X_s \gamma$, $B_d \rightarrow \phi K$, $B_d \rightarrow K\pi$, ...</td>
<td>$B_d \rightarrow X_d \ell^+ \ell^-$, $B_d \rightarrow X_d \gamma$, $B_d \rightarrow \pi \pi$, ...</td>
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</tr>
<tr>
<td><strong>$Z^0$ penguin</strong></td>
<td>$B_d \rightarrow X_s \ell^+ \ell^-$, $B_s \rightarrow \mu \mu$, $B_d \rightarrow \phi K$, $B_d \rightarrow K\pi$, ...</td>
<td>$B_d \rightarrow X_d \ell^+ \ell^-$, $B_d \rightarrow \mu \mu$, $B_d \rightarrow \pi \pi$, ...</td>
<td>$\varepsilon'/\varepsilon$, $K_L \rightarrow \pi^0 l^+ l^-$, $K \rightarrow \pi \nu \nu$, $K \rightarrow \mu \mu$, ...</td>
</tr>
<tr>
<td><strong>$H^0$ penguin</strong></td>
<td>$B_s \rightarrow \mu \mu$</td>
<td>$B_d \rightarrow \mu \mu$</td>
<td>$K_{L,S} \rightarrow \mu \mu$</td>
</tr>
</tbody>
</table>

of Gino Isidori
Even theory has its limitations

<table>
<thead>
<tr>
<th></th>
<th>Decreasing</th>
<th>SM</th>
<th>Contrib.</th>
</tr>
</thead>
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<tr>
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<tr>
<td>$\gamma$ penguin</td>
<td>$B_d \rightarrow X_s \gamma$, $B_d \rightarrow X_s \gamma$</td>
<td>$B_d \rightarrow X_d \gamma$, $B_d \rightarrow X_d \gamma$</td>
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</tr>
</tbody>
</table>

Theoretical errors $\lesssim 10\%$

by Gino Isidori
And experiments have no less

<table>
<thead>
<tr>
<th>ΔF=2 box</th>
<th>ΔF=1 4-quark box</th>
<th>ΔF=1 gluon penguin</th>
<th>ΔF=1 γ penguin</th>
<th>ΔF=1 Z⁰ penguin</th>
<th>ΔF=1 H⁰ penguin</th>
</tr>
</thead>
<tbody>
<tr>
<td>b → s (∼λ²)</td>
<td>b → d (∼λ³)</td>
<td>s → d (∼λ⁵)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ΔM_{Bs}</td>
<td>ΔM_{Bd}</td>
<td>ΔM_{K^0} ε_K</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>A_{CP}(B_s → ψφ)</td>
<td>A_{CP}(B_d → ψK)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- B_d → φK
- B_d → Kπ, ...
- B_d → ππ, B_d → ρπ, ...
- ε'/ε, K → 3π, ...

- B_d → X_s γ
- B_d → φK
- B_d → Kπ, ...
- B_d → X_d γ
- B_d → ππ, ...
- ε'/ε, K_L → π⁰γγ, ...

- B_d → X_s γ
- B_d → φK
- B_d → Kπ, ...
- B_d → X_d γ
- B_d → ππ, ...
- ε'/ε, K_L → π⁰γγ, ...

- B_s → μμ
- B_d → μμ

- K → πνν, K → μμ, ...

Gino Isidori

○ = exp. error ~ 10%
○ = exp. error ~ 100%
where are we?

\[ K^+ \rightarrow \pi^+ \nu \bar{\nu} \]

\[ K_L \rightarrow \pi^0 \nu \nu \]

\[ K_L \rightarrow \pi^0 e^+ e^- \quad [K_S \rightarrow \pi^0 e^+ e^-] \]
**K → πν¯ν** at Hadron Machines

David E. Jaffe, BNL

Overview

<table>
<thead>
<tr>
<th>Expt</th>
<th>Mode</th>
<th>Results or Goal</th>
</tr>
</thead>
<tbody>
<tr>
<td>E787</td>
<td>K⁺ → π⁺ν¯ν</td>
<td>Completed. 2 candidates.</td>
</tr>
<tr>
<td>E949</td>
<td>K⁺ → π⁺ν¯ν</td>
<td>1/5 completed. O(10) SM events</td>
</tr>
</tbody>
</table>

\[ \mathcal{B}(K^+ \rightarrow \pi^+ \nu \bar{\nu}) \]

<table>
<thead>
<tr>
<th>Measurement</th>
<th>(1.57^{+1.75}_{-0.82}) \times 10^{-10} (a)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Expectation</td>
<td>(0.7 \pm 0.2) \times 10^{-10} (d)</td>
</tr>
<tr>
<td></td>
<td>(0.7 \pm 0.1) \times 10^{-10} (e)</td>
</tr>
</tbody>
</table>

\[ \lambda V_{cb} \]

\[ \rho \]

\[ \gamma \]

\[ \alpha \]

\[ \beta \]

\[ \eta \]
Upgrades to E787:
Improved photon veto hermeticity
Improved tracking resolution
Higher rate and duty factor
2002 run ≤ E787 sensitivity,
~ 20% of E949 sensitivity goal of < 10^{-11}.

pnn1 results: fall 2003.
Not optimal in 2002:
1. Spill duty factor.
2. Proton beam momentum.

Clouds on future: cross the fingers
Status of KEK-E391a and Future Prospects on $K_L \rightarrow \pi^0 \nu \bar{\nu}$ at KEK

GeiYoub Lim
IPNS, KEK

What shall we do?

- Clear single $\pi^0$
  - $\pi^0 \rightarrow \gamma \gamma$ for high sensitive measurement
- Confirm no other accompanying particle
  - Perfect veto system
- Complete understand of background
  - Based on data with help of M.C.
- A huge amount $K_L$ decays
  - High intensity $K_L$ beam line, Large acceptance
E391a detector

Engineering run

$\sigma_{m\pi^0} = \text{[chart]}$
**Summary**

- **KEK-PS E391a**
  - The first dedicated experiment for the $K_L \rightarrow \pi^0 \nu \nu$
  - Detector is constructed on schedule for Feb. 2004
  - Aiming to $3 \times 10^{-10}$ S.E.S.
  - Significant step to the precise measurement

**Schedule**

- **Aug.**
  - FB assembling
  - CB fabrication
  - Middle section fabrication
  - Check Membrane
  - Downstream vacuum test
  - CC94/CC05 Fabrication

- **Sep.**
  - CB assembling
  - Cosmic and evacuate test for the upstream
  - CV PMT install
  - A/D Card upgrade
  - ADC Replacement

- **Oct.**
  - Moving downstream
  - Additional Cabling
  - CC94 Installation

- **Nov.**
  - CB assembling
  - BCV
  - Membrane
  - Unite three sections
  - BA and CC05 installation

- **Dec.**
  - BA and CC05 installation

- **Jan.**
  - Start data taking
  - Evacuate system

- **Feb.**
  - Cosmic test
Rare $K_L$ Decays
Recent Results from KTeV

Marj Corcoran
Rice University
for the KTeV collaboration

- Best limits on modes with possible direct CP-violating contributions
  - $K_L \rightarrow \pi^0 ee$
  - $K_L \rightarrow \pi^0 \mu\mu$
  - $K_L \rightarrow \pi^0 \nu\nu$
Experiment: $K_L \rightarrow \pi^0 ee (\mu \mu)$

<table>
<thead>
<tr>
<th>Mode</th>
<th>Upper Limit 90% CL</th>
<th>Ref.</th>
</tr>
</thead>
<tbody>
<tr>
<td>$K_L \rightarrow \pi^0 ee$</td>
<td>$&lt; 5.1 \times 10^{-10}$</td>
<td>PRL86 (2001) 97 data</td>
</tr>
<tr>
<td></td>
<td>$&lt; 2.8 \times 10^{-10}$</td>
<td>Preliminary 97+99</td>
</tr>
<tr>
<td>$K_L \rightarrow \pi^0 \mu \mu$</td>
<td>$&lt; 3.8 \times 10^{-10}$</td>
<td>PRL84 (2000)</td>
</tr>
</tbody>
</table>

A tiny (!!??) factor 10 away
BTW looking at very rare we shall not overlook some duty we have

The present situation is rather confused [large SU(2) breaking= wrong th. corrections, or bad data]...

...but in a short-time [with the help of KLOE data on both modes], we should be able to clarify it.

uncertainty dominated by the th. error on $f(0)$?
Future (semi-solid or rather liquid) in $K^+ \rightarrow \pi^+ \nu\bar{\nu}$
Status as of today

Dear Fred:

I am submitting the first report of the Particle Physics Project Prioritization Panel (P5) to HEPAP for consideration and forwarding to the DOE and the NSF. The P5 Subpanel of HEPAP was formed based on the November 6, 2009, decision to split the P5 into two subpanels, one for collider physics and one for detector development. The P5 Subpanel for Collider Physics, under the leadership of Joe Hill, was charged with conducting the analysis for the following priority areas:

- BTeV
- CKM
- LHC
- Higgs Physics
- Neutrino Physics
- HEP Accelerator R&D

The present Fermilab plan calls for a similar funding profile and time-line for BTeV and CKM construction, with both starting to take data around 2009. The P5 Subpanel believes that this plan is likely to be too ambitious given the need to optimize the physics from the Tevatron Collider, as well as the desire to have BTeV completed promptly. Based on current budgetary models, P5 does not recommend proceeding with CKM.
Future (same state of condensation) in $K_L^0 \rightarrow \pi^0 \nu \bar{\nu}$
KOPIO: myth or reality?
K_L \to \pi^0 \nu \nu at the J-PARC

- Large Number of K_L Decay
  - Three orders larger K_L flux
- Experience at KEK-PS
- Fast Electronics
  - High counting rates
- Optimization of beam line
  - K_L/n/\gamma ratio, \Lambda production
- Detector Up-grade
  - Calorimeter
    - fast response
    - Granularity
- Veto system
  - Detection efficiency
  - Become thicker (?)

<table>
<thead>
<tr>
<th></th>
<th>BNL</th>
<th>KEK</th>
</tr>
</thead>
<tbody>
<tr>
<td>Proton energy</td>
<td>24 GeV</td>
<td>120 GeV</td>
</tr>
<tr>
<td>Protons/pulse</td>
<td>5 \times 10^{10}</td>
<td>3 \times 10^{13}</td>
</tr>
<tr>
<td>Cycle time</td>
<td>3.6 sec</td>
<td>5 sec</td>
</tr>
<tr>
<td>Fluctuation</td>
<td>1.6 sec</td>
<td>1.0 sec</td>
</tr>
<tr>
<td>Ext. angle</td>
<td>45^\circ</td>
<td>4^\circ</td>
</tr>
<tr>
<td>Beam profile</td>
<td>4\text{mm} \times 125\text{mm}</td>
<td>0.22\text{mm} \times 0.22\text{mm}</td>
</tr>
<tr>
<td>Solid angle</td>
<td>500\text{mstr}</td>
<td>0.048\text{mstr}</td>
</tr>
<tr>
<td>$Y_{K_3} / p/\text{str}$</td>
<td>$4.8 \times 10^{-3}$</td>
<td>$4.8 \times 10^{-3}$</td>
</tr>
<tr>
<td>$K^0_L$ mom.</td>
<td>0.7 GeV/c</td>
<td>70 GeV/c</td>
</tr>
<tr>
<td>Decay region</td>
<td>0.35 m</td>
<td>0.35 m</td>
</tr>
<tr>
<td>Decay prob.</td>
<td>16%</td>
<td>12%</td>
</tr>
<tr>
<td>$K_L^- / p$</td>
<td>1.2 \times 10^8</td>
<td>2.3 \times 10^7</td>
</tr>
<tr>
<td>$K_L^0$ - decay/pulse</td>
<td>$3.1 \times 10^{10}$</td>
<td>$3.8 \times 10^{10}$</td>
</tr>
<tr>
<td>Inst. decay-rate</td>
<td>12 kHz</td>
<td>11 kHz</td>
</tr>
<tr>
<td>Acceptance</td>
<td>1.6%</td>
<td>7.4%</td>
</tr>
<tr>
<td>Run Time</td>
<td>3 \times 10^{13} sec</td>
<td>3 \times 10^{13} sec</td>
</tr>
<tr>
<td>Running Eff.</td>
<td>50%</td>
<td>50%</td>
</tr>
<tr>
<td>Sensitivity</td>
<td>1 \times 10^{-10}</td>
<td>1 \times 10^{-10}</td>
</tr>
<tr>
<td>Events (3 \times 10^{11})</td>
<td>38 events</td>
<td>1000 events</td>
</tr>
</tbody>
</table>

T. Inagaki, CP Violation in K (1998)
Future (gaseous) in $K_L \to \pi^0 \text{ee(}\mu\mu\text{)}$ Perspectives

*Admittedly aggressive Road Map*

- **Detector $\sigma(\gamma\gamma)$** $\times 2$
  - Very ambitious, KTeV/NA48 already state of the art
- **$K_S - K_L$ time dependent interference** $\times 2$
  - Position experiment between 9 and 16 $K_S$ lifetimes (hep-ph/0107046)
- **$K_S - K_L$ time independent interference** $\times 3$
  - Assume constructive interference (theoretically preferred)
- **Data Taking** $\times 5$
  - Run in "factory mode". After all E799-II run only for a few months to collect $\sim 7 \times 10^{11}$ $K_L$ decays
- **Beam intensity** $\times 4$
  - Need $\sim 10^{12}$ protons/sec, slowly extracted, high energy, DC
- **Tot $\sim \times 240 \rightarrow$ sens$\sim \times 15$
  - close the gap between current upper limit and SM
- **Where? When?**

**NA48/3 ??**

- CERN is currently the only place where high energy kaon beams could be employed
Future (unknown state of matter)

\[ K_L \rightarrow \pi^0 \nu \bar{\nu} \text{ at a } \Phi \text{ factory?} \]

Production rate: \(10^6 K_S - K_L\) pairs / pb\(^{-1}\)

1 year @ \(10^{35}\) cm\(^{-2}\)s\(^{-1}\): \(10^{12}\) \(K_L\) produced

observed decays: 30 \(\epsilon_{\text{tot}}\) / year (SM)

must be \(\epsilon_{\text{tot}} \geq 10\%\)

The search for \(K_L \rightarrow \pi^0 \nu \bar{\nu}\) is probably the most exciting goal and solid motivation for the high luminosity option of DAΦNE 2 (see Gino's talk yesterday)

It requires however luminosities of order \(10^{35}\) cm\(^{-2}\)s\(^{-1}\)
Future (unknown state of matter)

1 year @ $10^{32} = 1 \text{ fb}^{-1} \approx 3 \times 10^9 \Phi \approx 3 \times 10^9 K^\pm$

- Allows few per mil measurement of $O(1\%)$ BRs
- $V_{us}$ @ / below 1% (theor. error…?)
- $\delta_g(K^\pm \rightarrow \pi^\pm 2\pi^0)$ below 1%

1 year @ $5 \cdot 10^{33} = 50 \text{ fb}^{-1} \approx 1.5 \times 10^{11} \Phi \approx 1.5 \times 10^{11} K^\pm$

- $\approx 2 \times 10^6 K^\pm \rightarrow e^\pm \nu$ produced
- $\approx 15$ $K^\pm \rightarrow \pi^\pm \nu \nu$ produced

1 year @ $10^{35} = 10^3 \text{ fb}^{-1} \approx 3 \times 10^{12} \Phi \approx 3 \times 10^{12} K^\pm$

- $\approx 300 K^\pm \rightarrow \pi^\pm \nu \nu$ produced

L. Passalacqua / LNF-INFN
& the KLOE $K^\pm$ group.
Future (unknown state of matter)

It looks like that KLOE is the most beautiful MC ever conceived

L. Passalacqua / LNF-INFN & the KLOE K± group.

ε_{START} = (2ε_a) \cdot 0.85 \cdot (2ε_a) \cdot 0.3 \sim 9\%
\( K \to \pi \nu \bar{\nu} / \text{year} \) @ \( \mathcal{L} = 10^{35} \text{ cm}^{-2} \text{s}^{-1} \)

<table>
<thead>
<tr>
<th>( \mathcal{L} \mu \text{b}^{-1}/\text{s} )</th>
<th>( \int \mathcal{L} \text{d}t \mu \text{b}^{-1} )</th>
<th>( N(K_L) )</th>
<th>( N(K^{\pm}) )</th>
</tr>
</thead>
<tbody>
<tr>
<td>( 10^5 )</td>
<td>( 10^{12} )</td>
<td>( 10^{12} )</td>
<td>( 3 \times 10^{12} )</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>( N(K_L) )</th>
<th>( \text{BR} )</th>
<th>( \epsilon )</th>
<th>( N(\pi \nu \bar{\nu}) )</th>
</tr>
</thead>
<tbody>
<tr>
<td>( 10^{12} )</td>
<td>( 2.7 \times 10^{-11} )</td>
<td>( 0.03 )</td>
<td>( 0.8 )</td>
</tr>
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</table>

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<thead>
<tr>
<th>( N(K^{\pm}) )</th>
<th>( \text{BR} )</th>
<th>( \epsilon )</th>
<th>( N(\pi \nu \bar{\nu}) )</th>
</tr>
</thead>
<tbody>
<tr>
<td>( 3 \times 10^{12} )</td>
<td>( 7.7 \times 10^{-11} )</td>
<td>( 0.09 )</td>
<td>( 21 )</td>
</tr>
</tbody>
</table>
A contribute to discussion

- A realistic Luminosity plan for Dafne2 might allow the observation (not the measurement) of $K^+ \rightarrow \Xi^+$ and likely not even so for $K_L \rightarrow \Xi^0$

- However the physics potential of a machine should not be a single although V.I.Measurement (see Paolo F. talk)
We are talking of ~2010

• A) SUSY does not exist

• B) SUSY will be discovered next year by LHC

• C) SUSY has been already discovered
A) SUSY does not exist

• Then I could not care less about yet another constrain on an already over-constrained unitary triangle
B) SUSY will be discovered next year by LHC

- Then we expect a BR for both K->\π channels Enhanced wrt. SM
- Observation might be more than enough
- Together the deviations most likely already observed in B decays (Ks et al.) it will a great thing for the experimenters locally and world-wide
**C) SUSY has been already discovered**

- Then Daφne2 as well as SuperB(elle) will, for a long time, be the only places to work on the characterization of the SUSY.

- A drop of water in the sea compared to NLC but they might exist while...