$K_L$EVER: An Experiment to Measure $BR(K_L^0 \rightarrow \pi^0 \nu \bar{\nu})$ at the CERN SPS

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On behalf of the $K_L$EVER collaboration
Check Unitarity with Rare Kaon Decays

\[ \text{BR}(K_L \rightarrow \pi^0 \nu \bar{\nu}) \]

\[ \text{BR}_{SD}(K_L \rightarrow \pi^0 \ell^+ \ell^-) \]

\[ \text{BR}(K^+ \rightarrow \pi^+ \nu \bar{\nu}) \]

\[ \text{BR}_{SD}(K_L \rightarrow \mu^+ \mu^-) \]

\[ \text{charm} \]
$K \rightarrow \pi \nu \bar{\nu}$: Clean

- GIM-suppressed; loops dominated by top
- Hadronic elements from measured Ke3 rates
- No long-distance contributions from intermediate photons
SM Expected Rates

\[ BR(K^+ \rightarrow \pi^+ \nu \bar{\nu}) = (0.84 \pm 0.10) \times 10^{-10} \]
\[ BR(K^0_L \rightarrow \pi^0 \nu \bar{\nu}) = (0.34 \pm 0.06) \times 10^{-10} \]

Buras et al., 2015
Sensitive to New Physics

\[ \mathcal{B}(K_L \rightarrow \pi^0 \bar{\nu} \nu) \quad [10^{-11}] \]

\[ \mathcal{B}(K^+ \rightarrow \pi^+ \nu \bar{\nu}) \quad [10^{-11}] \]

MFV:  
\[ \arg \Delta_L = \arg V_{td}V_{ts}^* \]

\[ \Delta_L \text{ or } \Delta_R \text{ only:} \]
\[ |\epsilon_K|^{\text{NP}} \propto \text{Im} \Delta_{L(R)}^2 / M_{Z^0}^2 \]

General NP  
\[ \propto \frac{|\Delta_L + \Delta_R| \times |\Delta_L^0|}{M_{Z^0}^2} \]

Current Status

- $BR(K^+ \rightarrow \pi^+ \nu \bar{\nu}) = 1.7 \pm 1.1 \times 10^{-10}$
  BNL E787 and 949 (7 events)
  NA62 (1 event)

- $BR(K^0_L \rightarrow \pi^0 \nu \bar{\nu}) < 30 \times 10^{-10}$ (90%)
  KEK E391a
  KOTO
KOTO

- 2013: Pilot run 100 hours
  - BR 90% CL $\leq 5.1 \times 10^{-8}$

- 2015: 40 KW beam power; $3 \times 10^{19}$ p on target
  - Single-event sensitivity $1.2 \times 10^{-9}$; expected background $0.88 \pm 0.18$; open signal box this Summer

- 2016 - 2017: 50 KW; $3 \times 10^{19}$ p on target
  - Inner barrel veto installed

- 2018 – 2021: 20+ months of running; reach 100 KW; detector upgrades continue; SM sensitivity

- Future: Intention to reach $\sim 100$ SM events sensitivity
At the SPS?

- High-energy kaons
  - Photon detection easier, but larger detection volume required
  - Photon vetoing needs to extend only to 100 mr (polar angle)

- Backgrounds
  - Primarily $K^0_L \rightarrow \pi^0 \pi^0$
  - Boosted hyperons ($\Lambda \rightarrow n\pi^0$)
  - Neutrons
Working Detector Design

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\[ K_L \quad \langle p_K \rangle = 40 \text{ GeV} \]
MEC: Shashlyk Calorimeter with Spy Tiles

- Based on PANDA forward Ecal (Protvino)
- Spy tiles: PID and shower depth
  - $\mu$, $\pi$, $n$ identification
  - Improved time resolution

First prototype assembled and tested at Protvino OKA beamline, April 2018
Detecting Low-Angle Photons from $K_L$ Decays

- Killing backgrounds in high-flux neutral beam
  - Converter to remove upstream photons
  - SAC to see decay photons, not neutrons
  - Studies ongoing with crystals

Tagged photon test beam setup:

Collaboration with AXIAL group to measure pair-production enhancement in crystals in a test beam
Beam

- Primary beam momentum: $p_0 = 400$ GeV
- Targeting angle: $\theta = 8.0$ mrad
- Secondary beam angular acceptance: $\Delta \theta = 0.4$ mrad, conical

![Graph showing $K_L$ and $\Lambda$ fluxes in beam with FLUKA simulation]
Beam

- 4.8 s spill (3 s effective); 16.8 s duty cycle
- Primary beam intensity: $2 \times 10^{13}$ p/spill
- $2.1 \times 10^{-5}$ $K^0_L$/proton; $\sim$2% decay in fiducial vol.
- 200 days/year data taking; 50% uptime
- $\sim$10% Acceptance of fiducial volume decays
- $\rightarrow \sim$12 reconstructed $K^0_L \rightarrow \pi^0 \nu \bar{\nu}$ /year; S/B $\sim$ 1

Current beamline and experimental area require significant upgrades
Sensitivity Studies

- 2 clusters in MEC far from beam line; no hits in other detectors (except PSD)

- $\gamma\gamma$ from $\pi^0$ in FV with large transverse momentum
Status and Timeline

- **2018 – 2021: Consolidation and Proposal**
  - Expression of Interest to CERN SPSC
  - CERN Physics Beyond Colliders study
  - Crystal pair-enhancement beam test
  - Design Consolidation
  - Proposal to SPSC

- **2020 – 2022: R & D**

- **2022 – 2025: Construction**
  - K12 beam test?

- **2024/5 -2026: Installation (LS3)**

- **2026/7: First data (Run 4)**
Conclusion

- Preliminary studies suggest a competitive decay-in-flight measurement of \( BR(K_L^0 \rightarrow \pi^0 \nu \bar{\nu}) \) is feasible
- Design challenges—primarily in background suppression and small-angle activity—remain
- Alternative detector elements being considered
- The intention is to begin taking data in LHC run 4
- Additional collaborators welcome
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