Measurement of $\Gamma(K^+ \to e^+\nu)/\Gamma(K^+ \to \mu^+\nu)$ And Search for Heavy Sterile Neutrinos Using The TREK Detector System

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Abstract:

In the world of weak interactions, do electrons and muons have the same properties? This is the underlying question regarding lepton flavor universality. The Standard Model (SM) prediction ratio of leptonic K+ decay widths $R_K = \Gamma(K^+ \to e^+ \nu)/\Gamma(K^+ \to \mu^+ \nu)$ is a highly precise value. The uncertainty of the SM value for this ratio is $\Delta R_K / R_K = 0.4 \times 10^{-3}$. The proposed experiment E-36 at J-PARC uses stopped K+ and the TREK (Time Reversal Experiment with Kaons) detector system to conduct a precision measurement of R_K. Any observed deviation from the SM prediction would yield clear indication of New Physics beyond the Standard Model. The aim is to achieve an uncertainty for R_K of better than $\Delta R_K / R_K = 2.5 \times 10^{-3}$. The second portion of the experiment searches for heavy sterile neutrinos (N) in the $K^+ \to \mu^+ N$ decay and allows for further stringent searches for light new particles from the hidden sector as a byproduct.

Search For Lepton Flavor Violation:

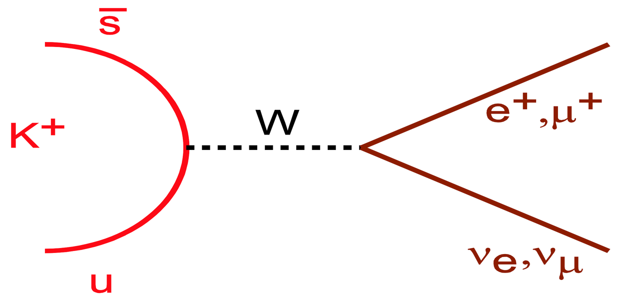
Lepton universality, a basic assumption of the SM, is expressed as an identical coupling constant of the three charged leptons:

e, μ and τ

High precision electroweak tests can be used to test SM predictions, while also obtaining hints of new physics. Violation of SM predictions is a clear indication of other physics beyond the SM.

Leptonic K^+ Decay Width Ratio

$$R_K^{SM} = \frac{\Gamma(K^+ \to e^+\nu)}{\Gamma(K^+ \to \mu^+\nu)} = \frac{m_e^2}{m_\mu^2}\left(\frac{m_K^2 - m_e^2}{m_K^2 - m_\mu^2}\right)^2 (1+\delta_r)$$



- **Highly precise SM value**

  $R_K^{SM} = (2.477 \pm 0.001) \times 10^{-5}$

- **High sensitivity to LFV beyond SM**

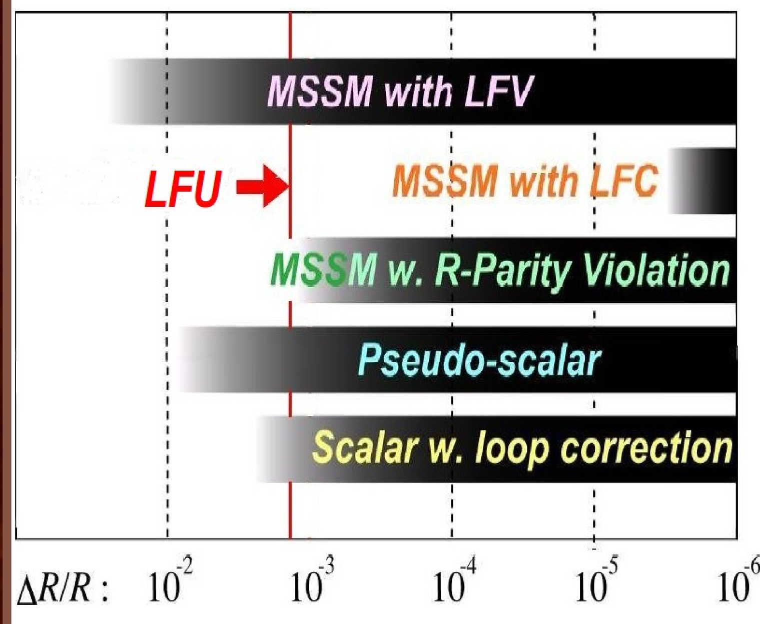
  MSSM with charged-Higgs SUSY-LFV

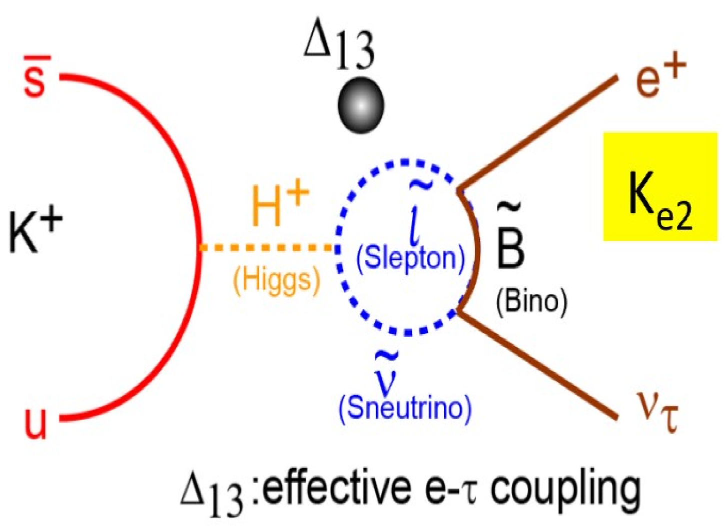
  - **Can strongly be enhanced by emission of τ neutrino (ν_τ)**

$$R_K^{LFV} = R_K^{SM}\left(1 + \frac{m_K^4}{M_{H^\pm}^4} \cdot \frac{m_\tau^2}{m_e^2}\Delta_{13}^2 \tan^6\beta\right)$$

The Factor $\left(\frac{m_\tau}{m_e}\right)^2$: **Can produce sizable effects in width of R_K through change of the K_{e2} width**

$\Rightarrow R_K^{LFV} \sim R_K^{SM}(1 \pm 0.013)$





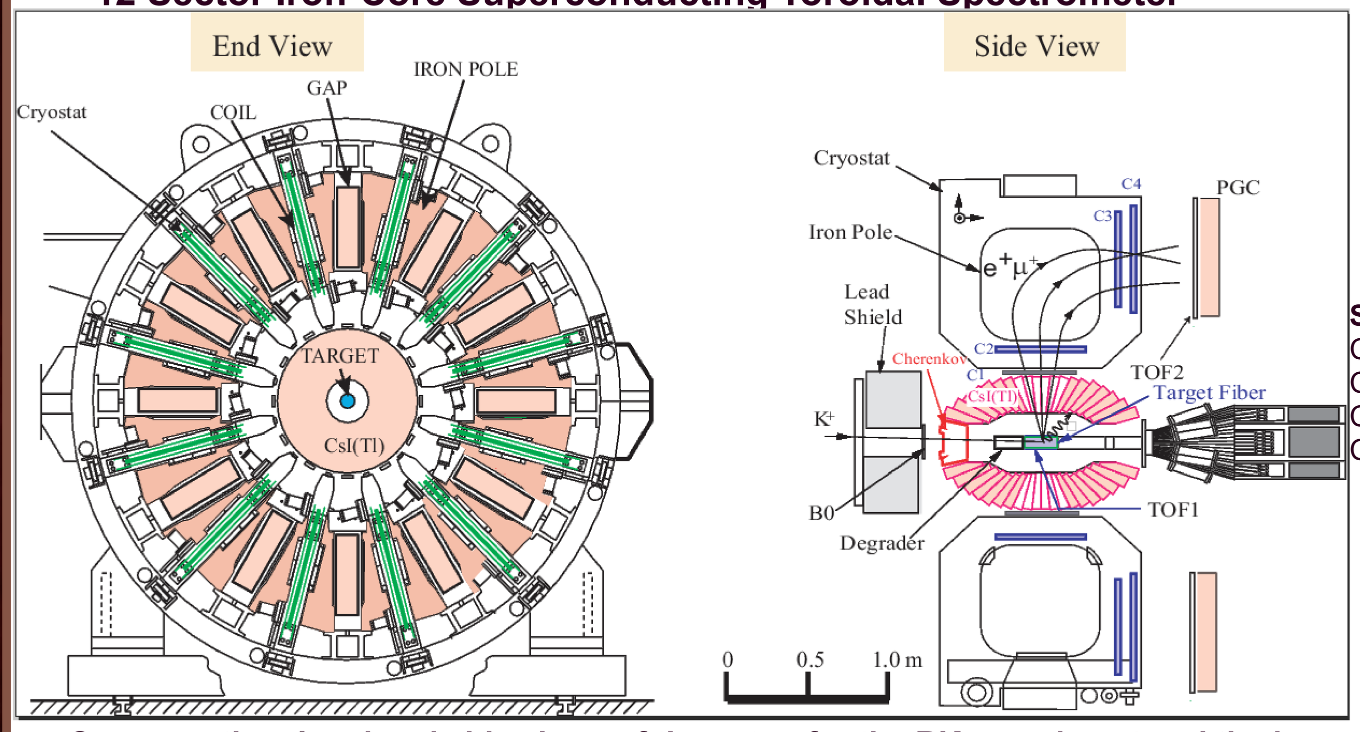
- **Current experimental precision (KLOE, NA62)**

  $R_K = (2.488 \pm 0.010) \times 10^{-5}$, $\Delta R_K / R_K = 0.4\%$

Improve precision to 0.25% (0.20%stat.+0.15% sys.)

E-36 TREK Detector System:

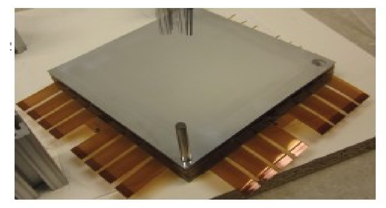
- **Stopped K+ beam (target)**
- **12 Sector Iron-Core Superconducting Toroidal Spectrometer**



Sub-Detector Components (KEY):
C1: Planar GEM 300x100mm²
C2: Planar MWPC 560x160mm²
C3: Planar MWPC 640x200mm²
C4: Planar MWPC 720x200mm²

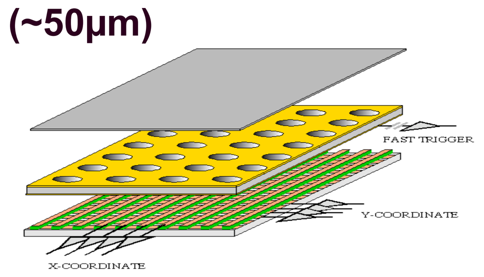
Cross sectional end and side views of the setup for the RK experiment and the heavy neutrino search

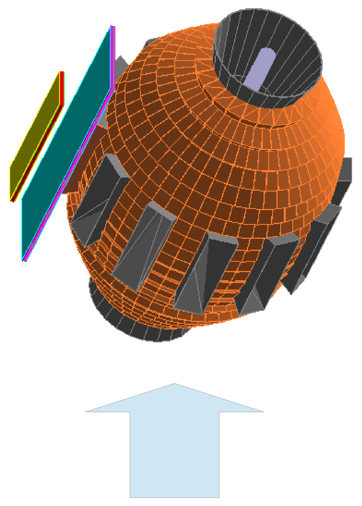
GEM Tracking Technology:



(Gas Electron Multiplier Detector)

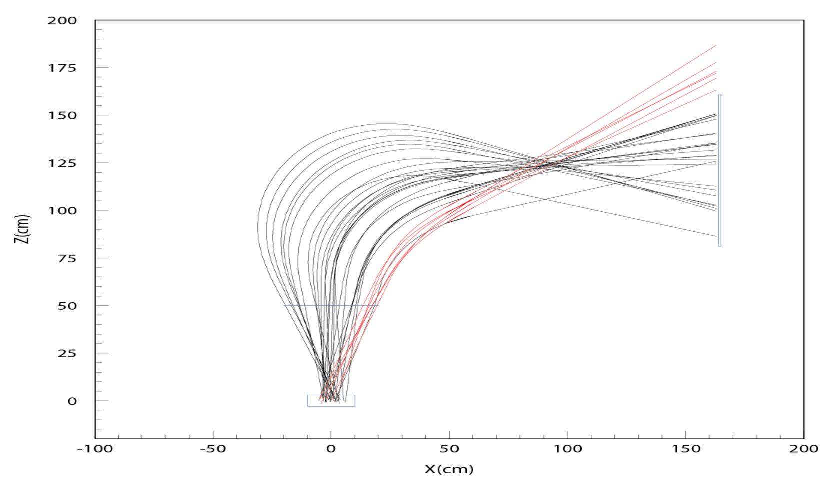
- **Double copper (~5μm) Kapton (~50μm)**
- **Thin metal-clad**
  - **Double conical shaped hole**
    - **Inner Diameter ~50μm**
    - **Outer Diameter ~70μm**
    - **Pitch Depth ~140μm**

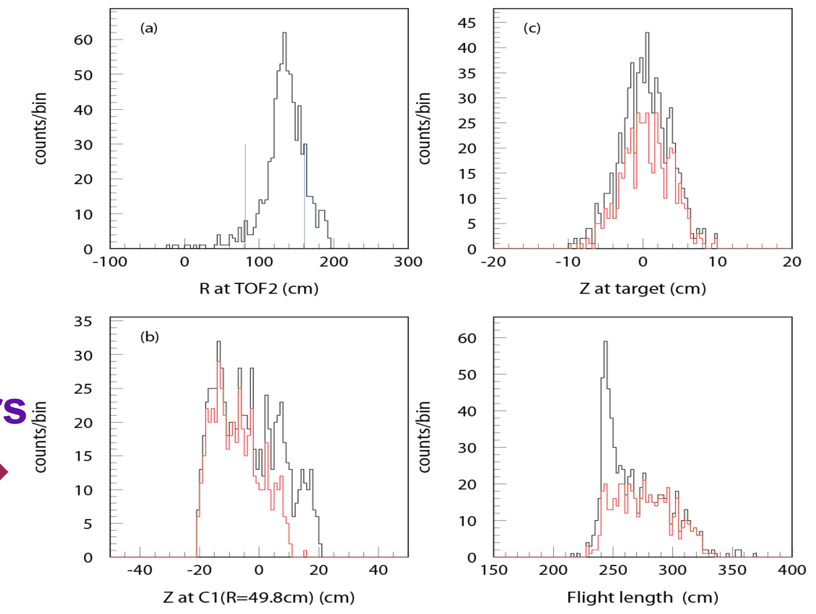




12 Planar Triple GEM Detectors GEMs cover muon holes of CsI(Tl) calorimeter

Charged Particle Tracking





Determining GEM Design Parameters

Computer Simulated Monte Carlo Hit Trajectories →

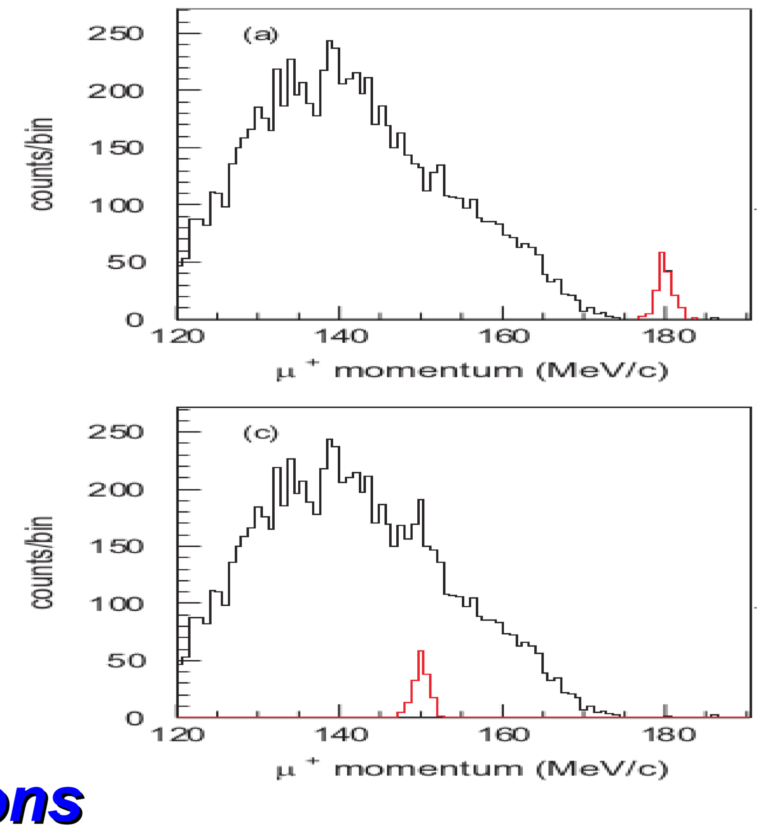
From Hit Trajectories → GEM (300x100mm²)

Searches:

Heavy Sterile Neutrinos

The search for heavy sterile neutrinos (N) in the $K^+ \to \mu^+ N$ decay will be conducted using a stopped K^+ beam. The neutrino minimal Standard Model (νMSM) predicts this branching ratio to be up to 10^{-6}. This decay has some important features:

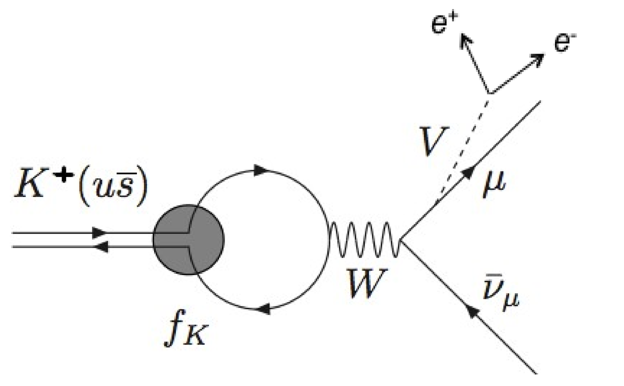
- Accessible by using the TREK experimental apparatus
- Narrow peak structure would be formed in the momentum spectrum
- Sensitive to $\Gamma(K^+ \to \mu^+ N) \sim 10^{-8}$
  - Main background from $K_{\mu 3}$



Dark Photon/U(1) Bosons

Full Reconstruction of Final State:

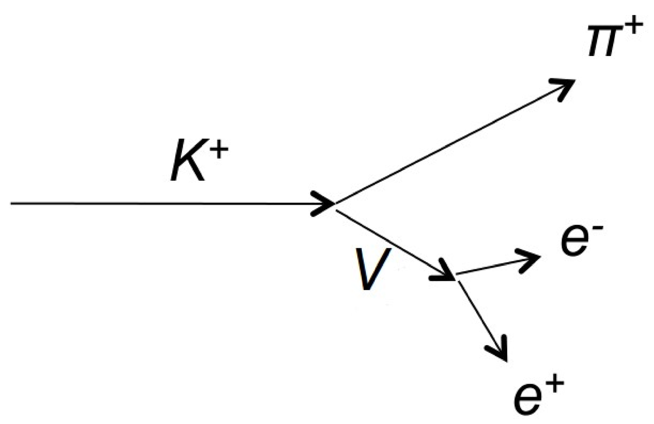
- Detection of all charged particles with good resolution



Decay Channel:
- $K^+ \to \mu^+ \nu e^+ e^-$

Signal: Search for narrow peak in (ee) invariant mass spectrum
- $V \to e^+ e^-$

Background:
- $Br(K^+ \to \mu^+ \nu e^+ e^-) \sim 2.5 \times 10^{-5}$



Decay Channel:
- $K^+ \to \pi^+ e^+ e^-$

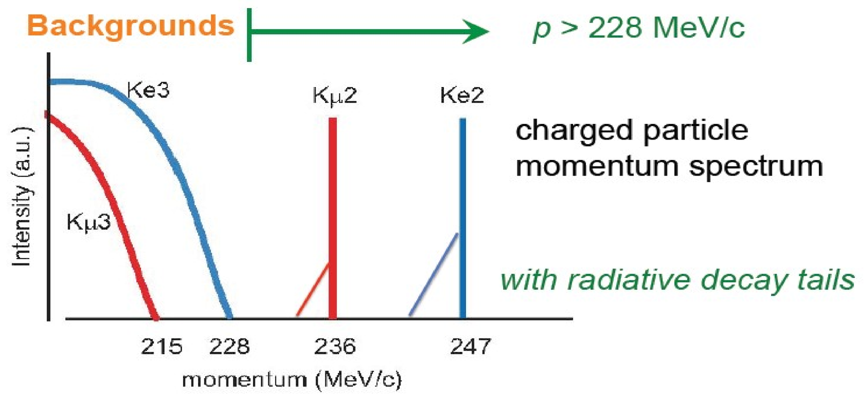
Signal: Search for narrow peak in (ee) invariant mass spectrum
- $V \to e^+ e^-$

Background:
- $Br(K^+ \to \pi^+ e^+ e^-) \sim 2.5 \times 10^{-7}$

Analysis Overview:

K_{e3} and $K_{\mu 3}$ Background Removal:

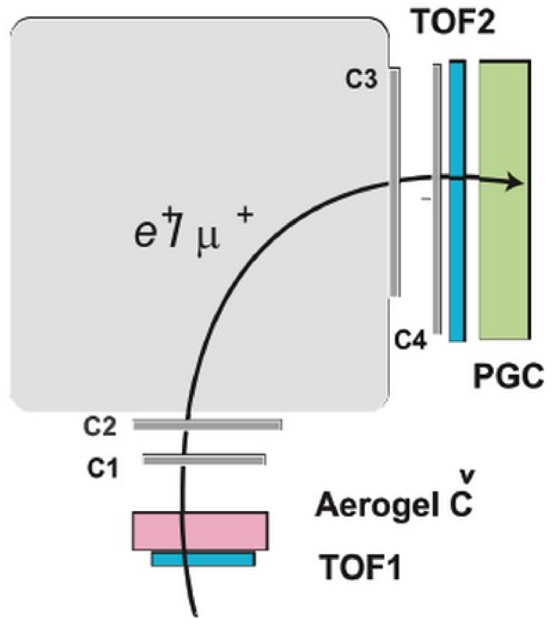
- e^+ and μ^+ momentum must be greater than K_{e3} and $K_{\mu 3}$
  - → **Observation of of K_{e2} and $K_{\mu 2}$**



Discrimination of $K_{e2}/K_{\mu 2}$

Discriminate between e/μ not only in momentum spectrum but also using Time Of Flight and Aerogel Cherenkov

Calibration of Particle (μ^+/e^+) Identification



Particle Identification:
- TOF
- Aerogel Cherenkov (AC)
- Lead Glass (PGC)

Efficiency Calibration:
- **"Sandwich Method"** using real K_{e2} data

Element for check	Tracking elements	PID
AC	C1, C2, C3, C4	TOF⊗PGC
TOF	C1, C2, C3, C4	AC⊗PGC
PGC	C1, C2, C3, C4	TOF⊗AC

References

http://trek.kek.jp/
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