Measurement of $\Gamma(K^+ \rightarrow e^+\nu)/\Gamma(K^+ \rightarrow \mu^+\nu)$ to search for lepton universality violation using a stopped K^+ beam

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on behalf of J-PARC E36 collaboration

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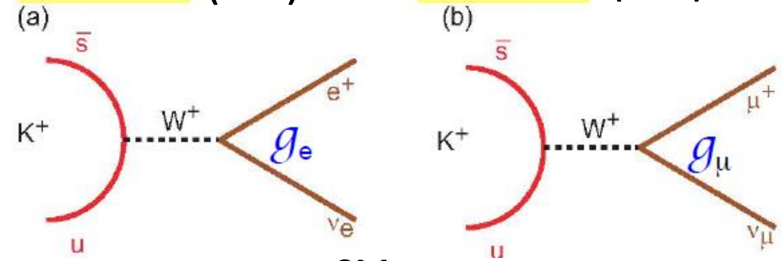
Search for Lepton universality violation in K_{l2} decays

- The J-PARC E36 experiment: precise measurement of decay width ratio

$$R_K^{\exp} = \frac{\Gamma(K^+ \rightarrow e^+\nu)}{\Gamma(K^+ \rightarrow \mu^+\nu)}$$

$K \rightarrow e\nu$ (K_{e2}) $K \rightarrow \mu\nu$ ($K_{\mu2}$)



- The hadronic form factors are cancelled out, and R_K^{SM} with radiative correction (δ_r) is highly precise. Deviation of R_K from SM indicates lepton universality violation.

$$R_K^{SM} = \frac{m_e^2}{m_\mu^2}\left(\frac{m_K^2 - m_e^2}{m_K^2 - m_\mu^2}\right)^2 (1+\delta_r) \; \mathbf{= (2.477 \pm 0.001)x10^{-5}}$$

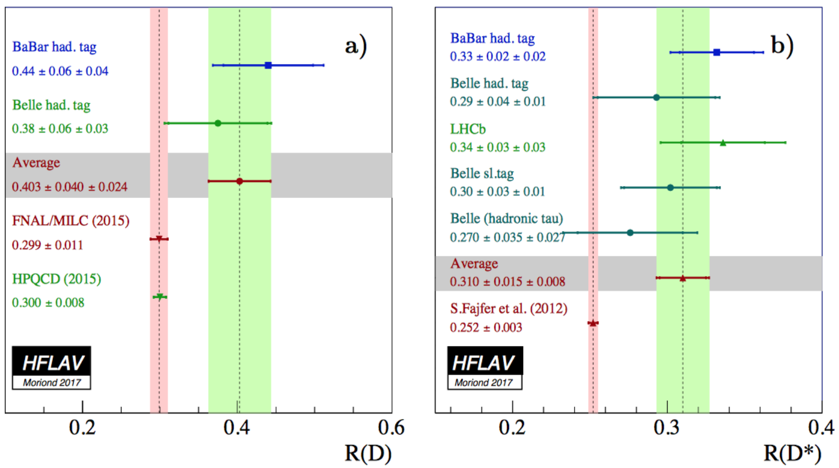
- The current PDG world average is **$(2.488 \pm 0.010)\mathrm{x}10^{-5}$**. It was obtained by an in-flight K^+ technique.

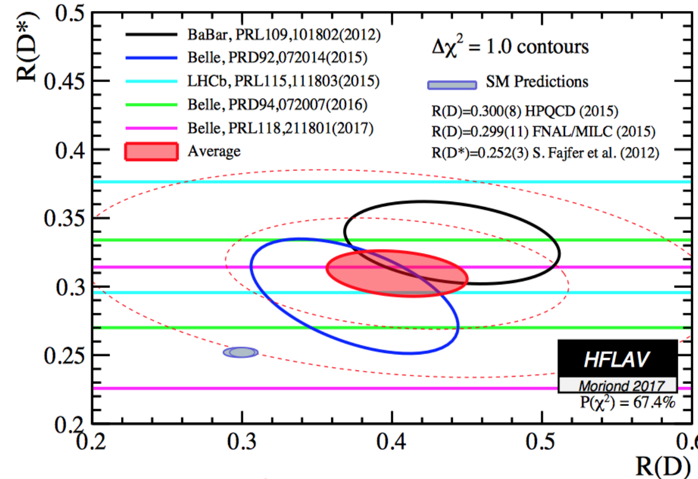
- In E36, a stopped K^+ method was adopted, which was totally different systematic conditions and worth determining the R_K value with comparable experimental uncertainty.

Lepton Universality Violation in B decays

Figures taken from reports by Heavy Flavor Averaging Group (2017) and LHCb (2017)

$$\mathcal{R}(D) = \frac{\mathcal{B}(B \to D\tau\nu_\tau)}{\mathcal{B}(B \to D\ell\nu_\ell)},\ \mathcal{R}(D^*) = \frac{\mathcal{B}(B \to D^*\tau\nu_\tau)}{\mathcal{B}(B \to D^*\ell\nu_\ell)}$$

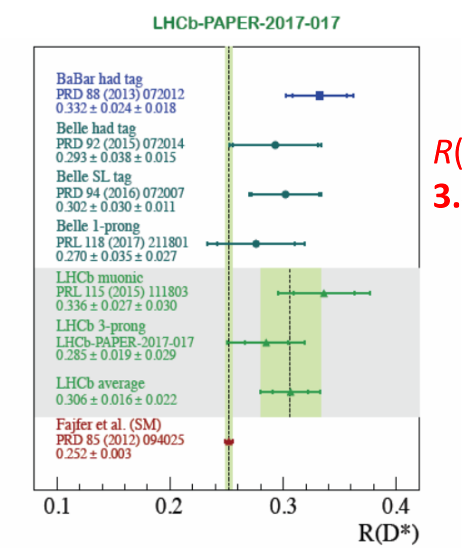




R(D)=0.403 ± 0.047; **2.2 σ** from the SM

R(D)/*R*(D*) combination

3.9 σ from the SM

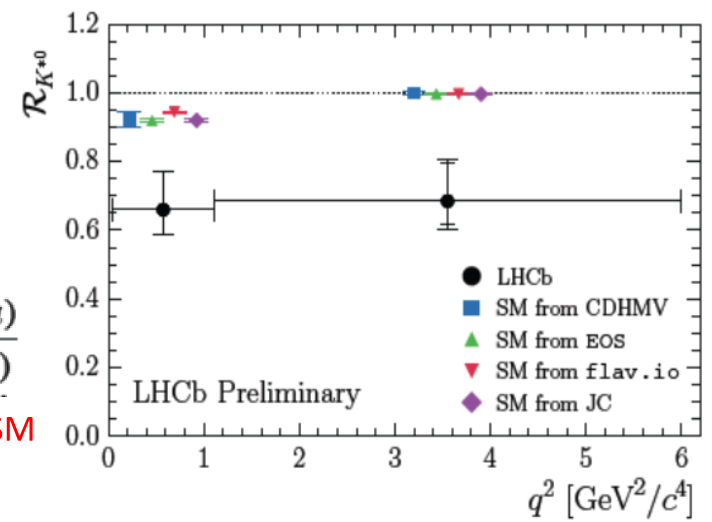


R(D*) = 0.305 ± 0.015

3.4 σ above the SM

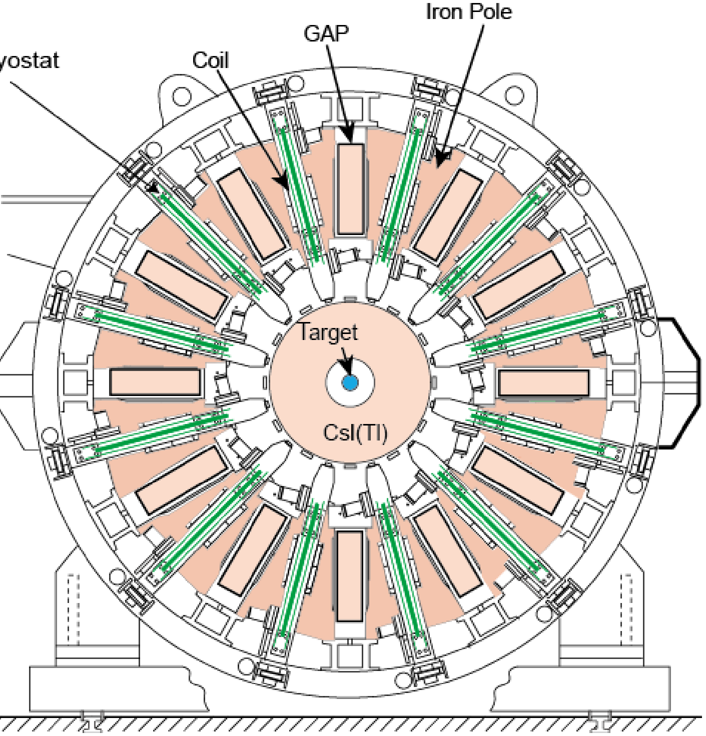
$$R_{K^{(*)}} = \frac{BR(B \to K^{(*)}\mu\mu)}{BR(B \to K^{(*)}ee)}$$

R(K) : **2.6 σ** from the SM

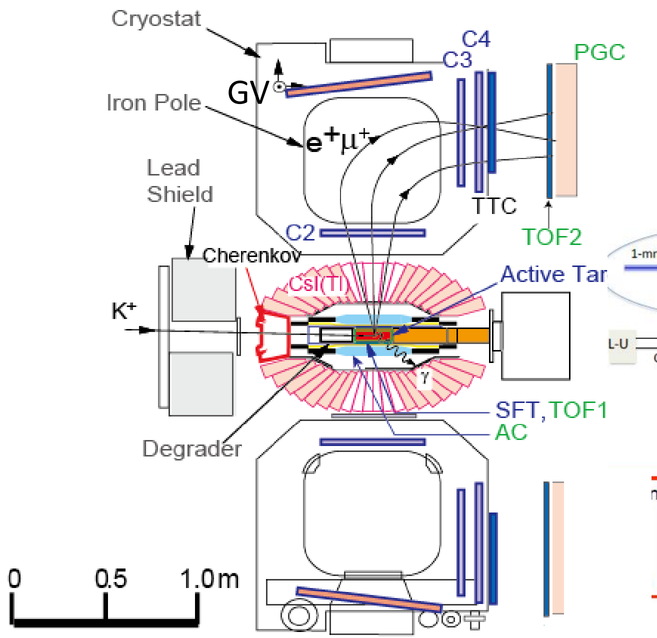


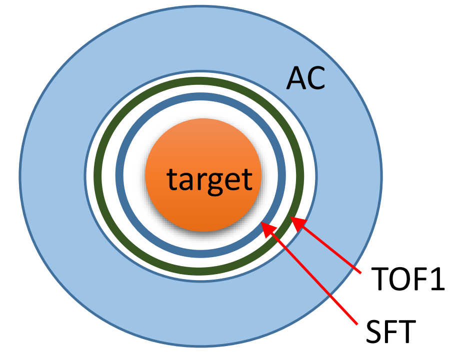
The J-PARC E36 experiment using a stopped K^+ beam

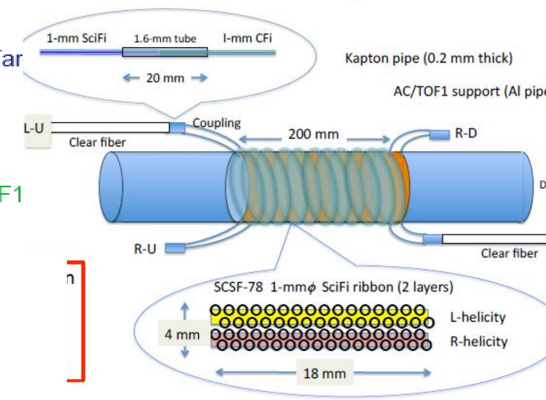
End View



Side View







Stopped K method

- K1.1BR beamline
- Beam Cherenkov
- K^+ stopping target

Tracking

- MWPC (C2, C3, C4)
- Spiral Fiber Tracker (SFT)
- Thin trigger counter (TTC)

PID

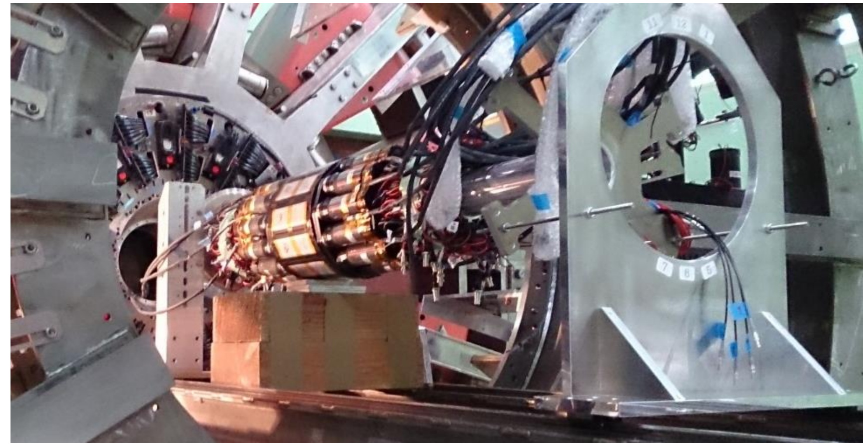
- TOF (TOF1, TOF2)
- Aerogel Cherenkov (AC)
- Pb glass counter (PGC)

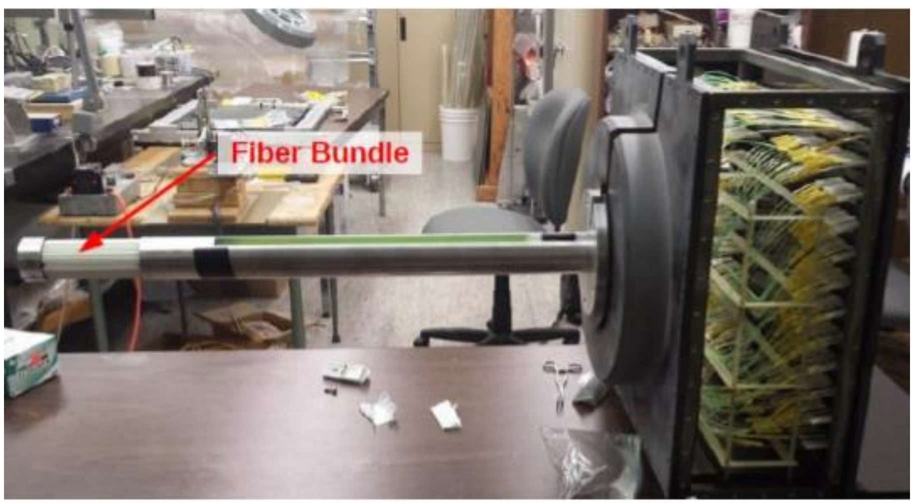
Gamma ray

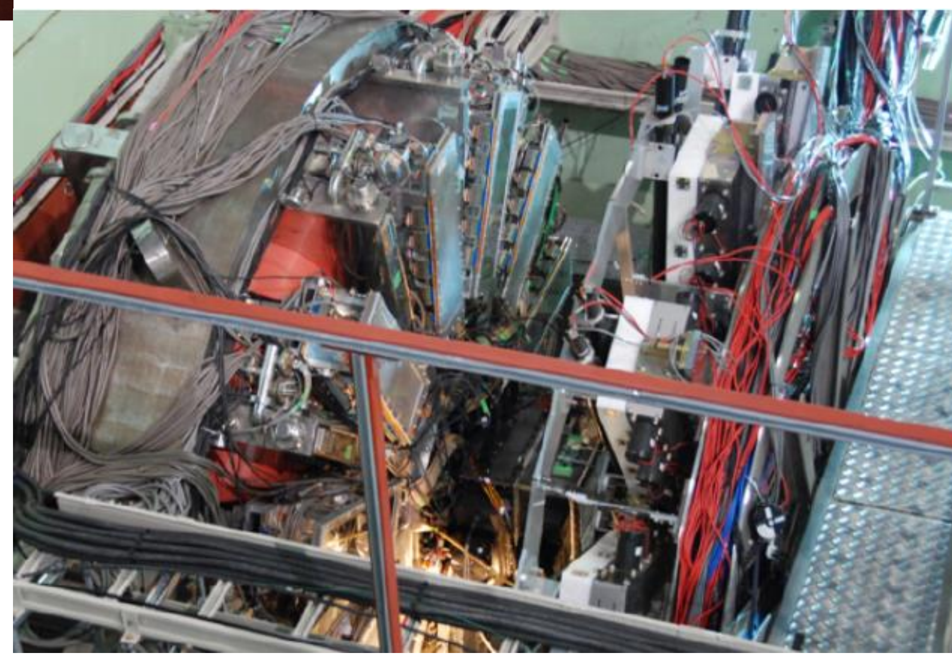
- CsI(Tl)
- Gap veto (GV)

The E36 experiment at J-PARC

- Magnet was moved to J-PARC, Dec. 2014
- Detector installation, till Apr. 2015
- Commissioning with a beam, till Oct. 2015
- Data collection, till Dec. 2015
- Detector dismantled, Mar. 2016

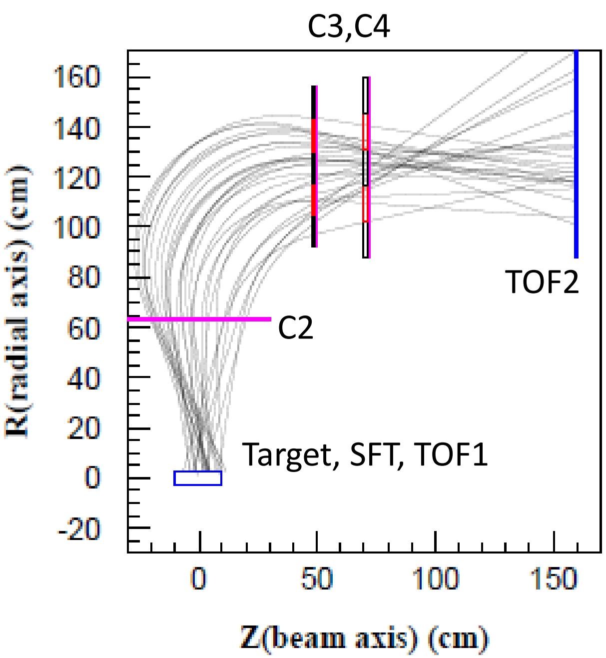


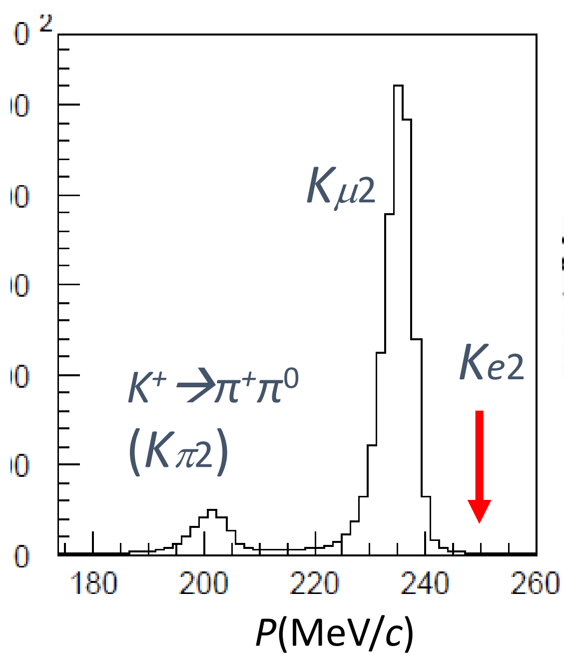

Fiber Bundle

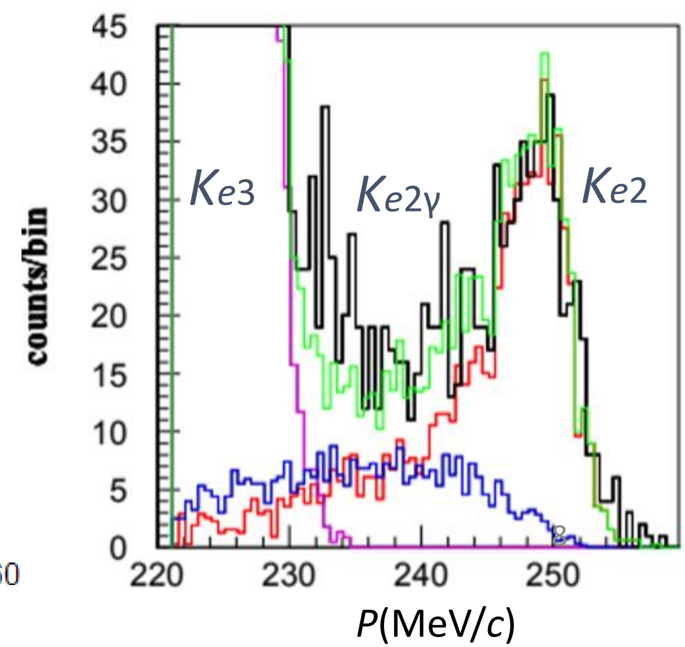


K_{e2} momentum spectrum

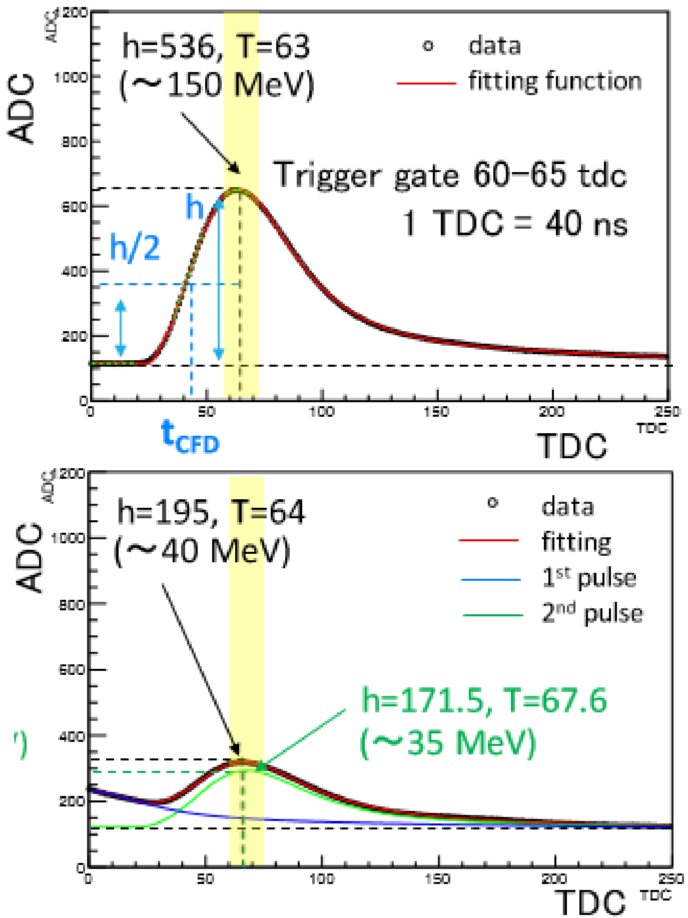
- The K_{e2} momentum spectrum was obtained by requiring PID detectors.
- Black histogram is the experimental data. Red, blue, and purple ones are the Monte Carlo simulation of K_{e2}, structure dependent $K^+ \to e^+ \nu \gamma$ ($K_{e2\gamma}$), and $K^+ \to \pi^0 e^+ \nu$ (K_{e3}) decays. Green one is sum of the three decays.



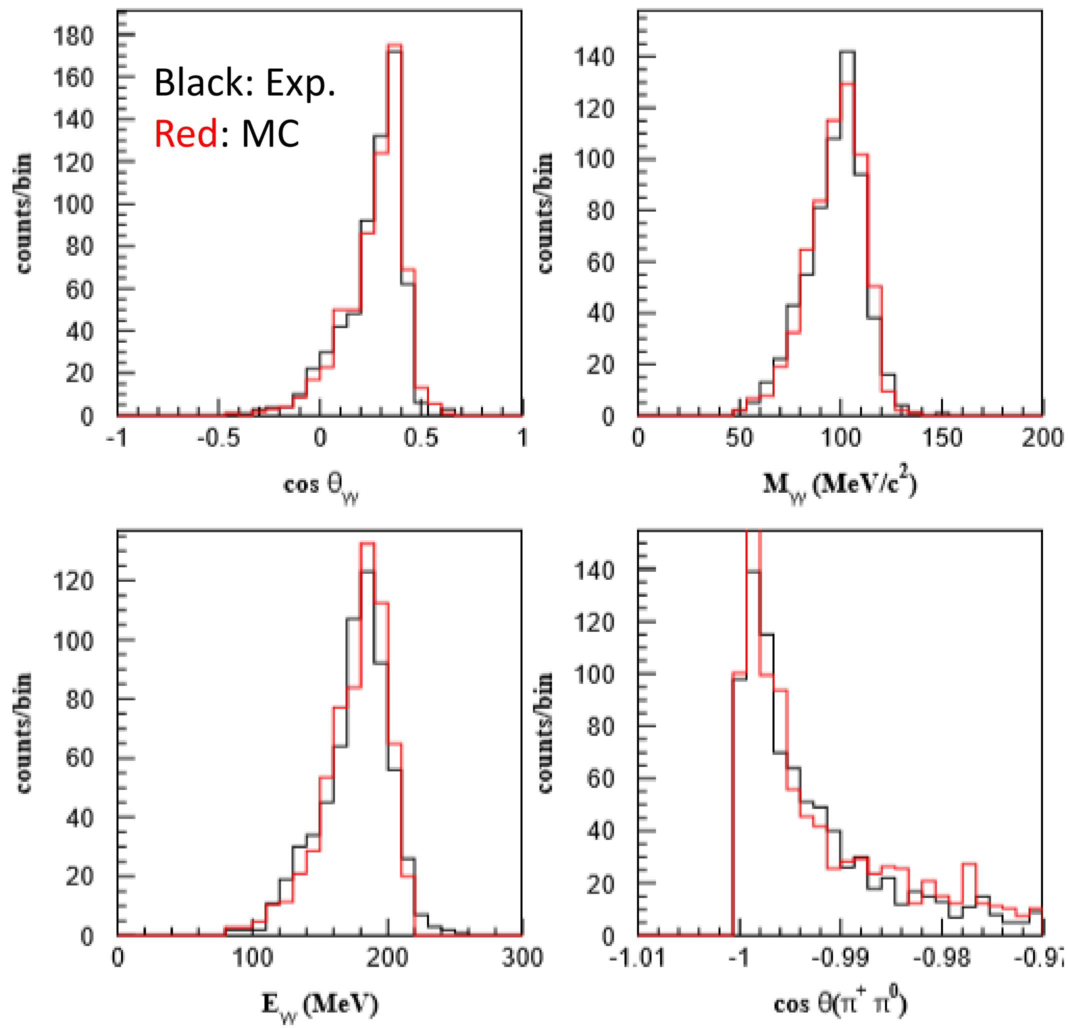




CsI(Tl) pulse shape analysis and its calibration using $K^+ \rightarrow \pi^+ \pi^0$ decay

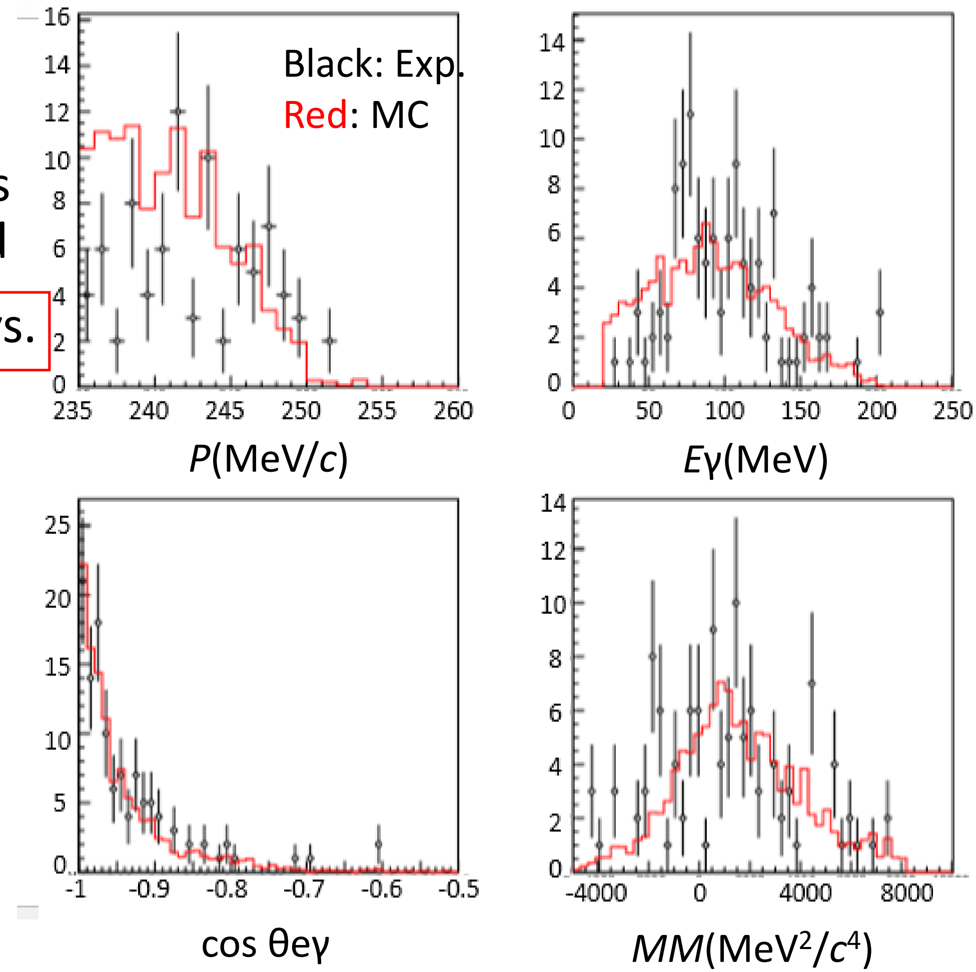


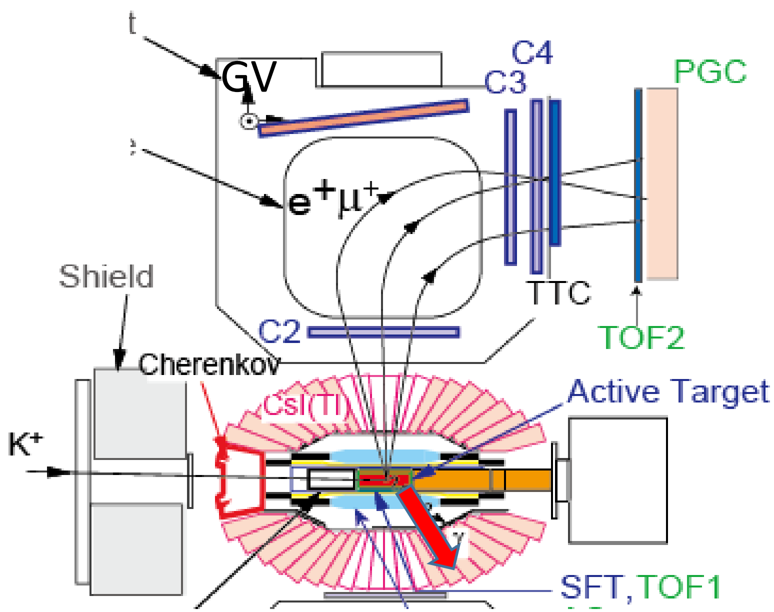
H. Ito et al., to be published in NIM-A



Analysis of structure dependent (SD) $K^+ \rightarrow e^+\nu\gamma$ decays

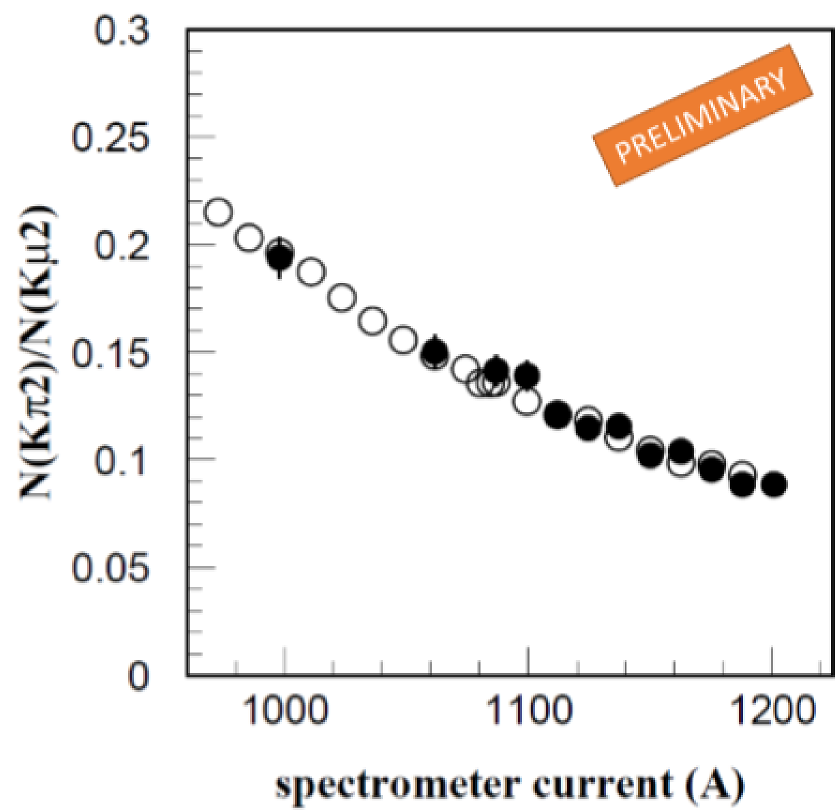
- The photon from the SD process tends to be emitted in opposite direction of e^+ motion. The photon energy from SD is higher than IB.
- Complete rejection of $K^+ \rightarrow \pi^0 e^+\nu$ decays is impossible. Missing Mass (*MM*) was used
- We can successfully extract SD $K_{e2\gamma}$ decays.





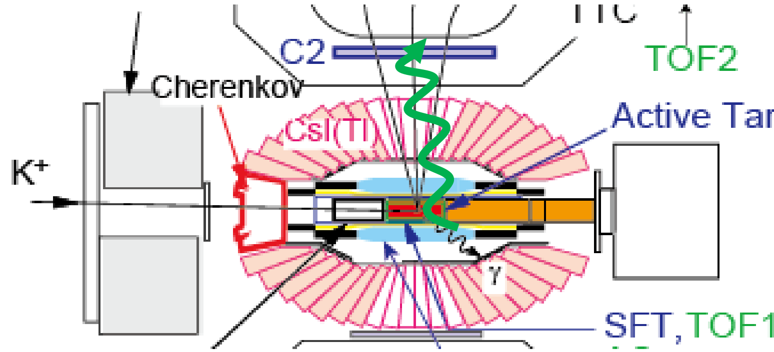
Systematic uncertainty: effect from $\Omega(K_{\mu 2})/\Omega(K_{e2})$ ratio uncertainty

- $N(K_{\pi 2})/N(K_{\mu 2})$ ratio is obtained as a function of the spectrometer field.
- The experimental results (open) are compared with the simulation calculation (closed).
- The difference is due to uncertainty of the spectrometer acceptance, which can be converted into $\Omega(K_{\mu 2})/\Omega(K_{e2})$ ratio uncertainty.
- The **preliminary** estimation is $\Delta R_K/R_K$~0.15%

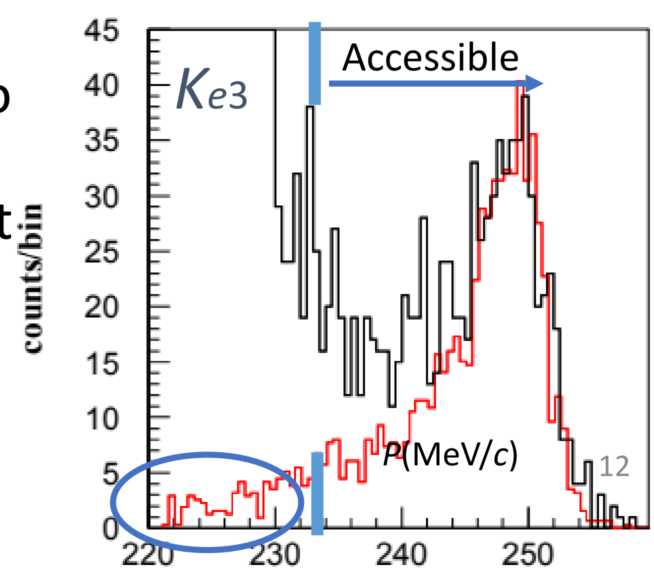


Systematic uncertainty: effect from wrong correction for the e^+ interaction with target material

- Disappearance of e^+ due to annihilati bremsstrahlung emission, and knock-on e^-. Red histogram is the K_{e2} simulation



- There are three causes of uncertainties. **Preliminary** estimations are:
  - Input of wrong K^+ stopping distribution to MC (<0.1%)
  - Imperfect reproducibility of MC for target assembly geometry (~0.1%)
  - Theoretical uncertainty of the adopted models in GEANT4 (~0.1%)



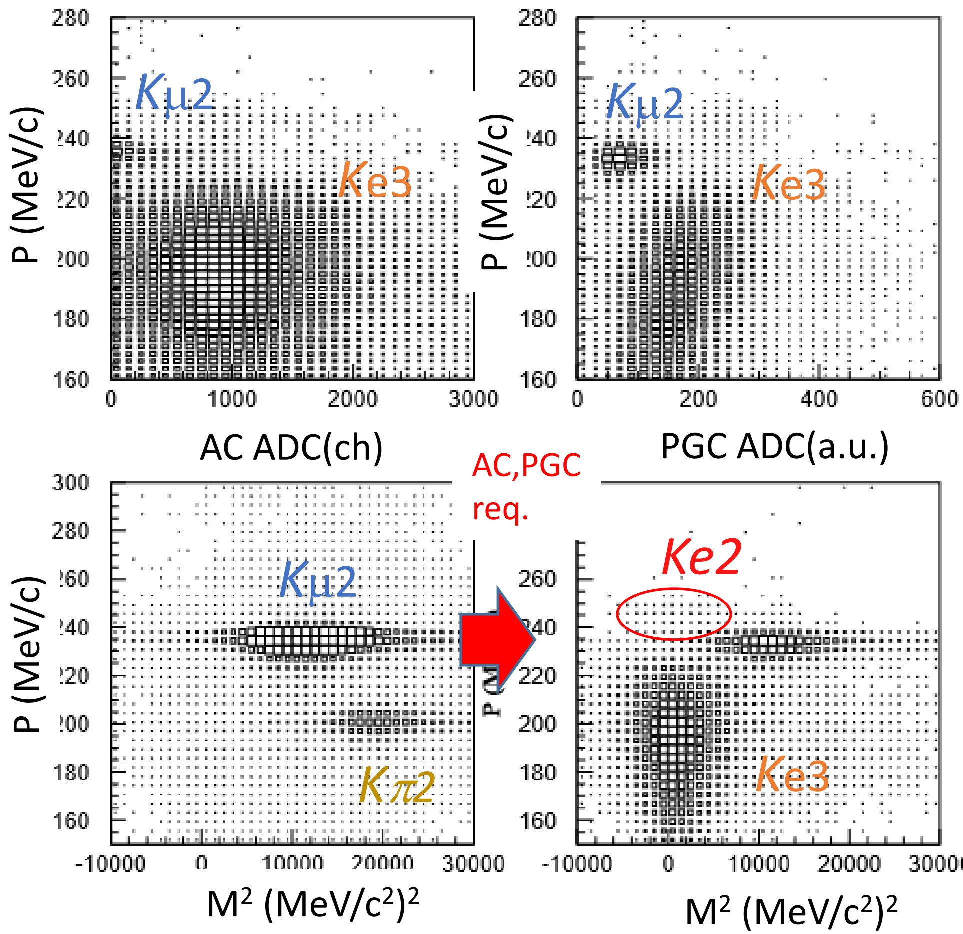
Summary

- The J-PARC E36 experiment is searching for Lepton universality violation in K_{l2} decays.
- The experiment was performed in 2015. Charged particle tracking, PID, CsI(Tl) analysis, etc., have been established.
- New analysis results taking into account K_{e2}, $K_{e2\gamma}$, and K_{e3} decays were reported.
- Estimation of the E36 systematic uncertainties is in progress
  - Reproducibility of the experimental condition by the Monte Carlo simulation for both charged particles and photons
  - Effect from $\Omega(K_{\mu2})/\Omega(K_{e2})$ ratio uncertainty
  - Uncertainty of the e^{+} interaction correction

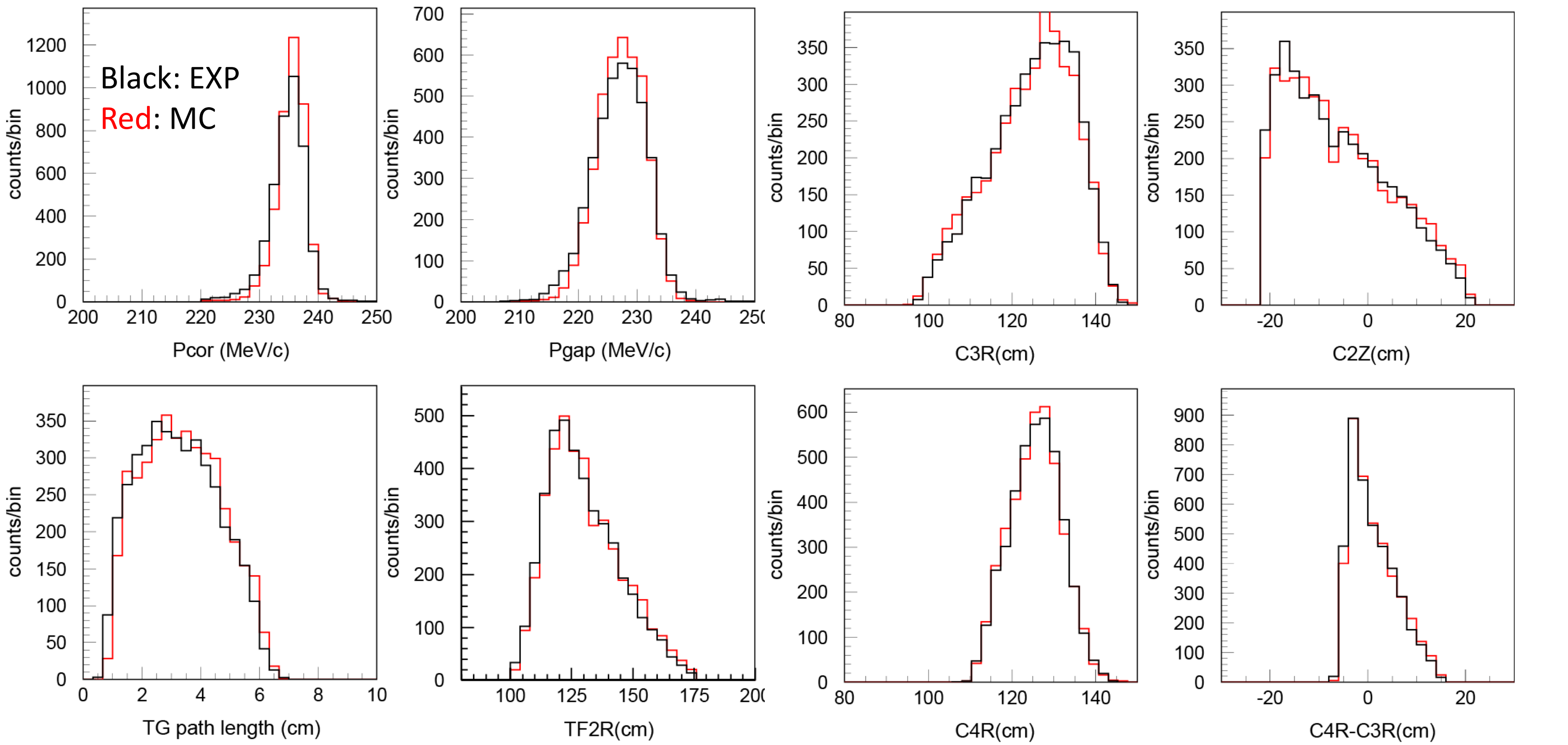
Backup slides

Particle Identification by AC, PGC, and TOF

- Positrons are selected by aerogel Cherenkov (AC), lead-glass Cherenkov (PGC), and TOF PID detectors.
- The PID performance by combining the three detectors is now being optimized.
- In addition, a likelihood method will be introduced for further muon suppression.



Comparison experimental spectra with MC using $K_{\mu 2}$ decay events



Fiber target analysis for stopped K^+s

- The K^+ life time curve was observed in the time interval spectrum of FC and TOF1. Prompt cut (Time>3ns) was applied to remove in-flight K^+ decays (Before, target fiber timing was used).
- Lepton track was reconstructed from the hit TOF1 to the K^+ clusters. Although about 20% events were rejected in this analysis, they can be recovered by introducing the new target code.
- Intersection point of the reconstructed track and K^+ cluster is regarded to be K^+ stopping position, which was obtained only using the target pattern information before.