

Probing New Physics With Experiment E36 at J-PARC

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for the TREK Collaboration

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New Physics beyond the Standard Model

Big questions

- *Baryogenesis*: Asymmetry of matter and anti-matter in universe
- Dark matter
- Dark energy etc.



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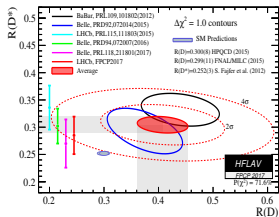
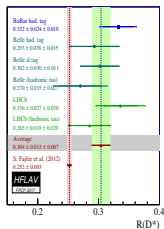


In the world of *weak interactions* do *electrons, muons and taus* behave the same way?

Lepton universality violation?

$\mu - \tau$

$$R_{D^{(*)}} = \frac{\mathcal{B}(B \rightarrow D^{*} \tau \nu)}{\mathcal{B}(B \rightarrow D^{*} \mu \nu)}$$

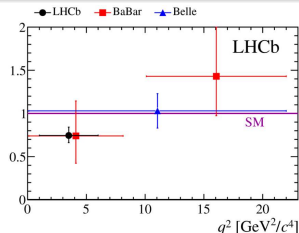


HFLAV average of combined $R(D)$ and $R(D^*)$ is 4.1σ from the SM prediction

Lupato (PANIC 2017)

$\mu - e$

$$R_K[q_{min}^2, q_{max}^2] = \frac{\int_{q_{min}^2}^{q_{max}^2} dq^2 \frac{d\Gamma(B \rightarrow K \mu^+ \mu^-)}{dq^2}}{\int_{q_{min}^2}^{q_{max}^2} dq^2 \frac{d\Gamma(B \rightarrow K e^+ e^-)}{dq^2}}$$



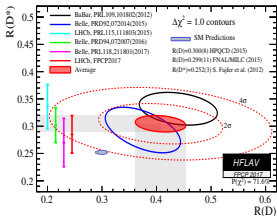
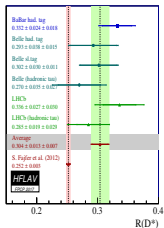
$$R_K = 0.745^{+0.090}_{-0.074} \pm 0.036 \text{ (sys)}$$

2.6 σ deviation!

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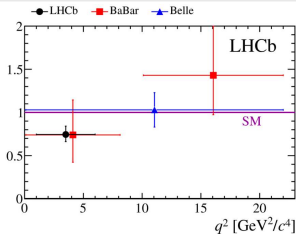


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Lepton non-universality is the flagship for physics beyond the Standard Model

Overview

- 1 Preliminaries
 - Lepton universality in K^+ decays
 - Detector geometry
- 2 Simulation and real geometry
 - Central detector system
- 3 Tracking & PID systems
 - Kalman Filter, magnetic field etc.
 - $K_{\mu 2}$ hit profile
 - $K_{\pi 2}$ tracks
 - PID systems
- 4 Closing

Outline

1 Preliminaries

- Lepton universality in K^+ decays
- Detector geometry

2 Simulation and real geometry

- Central detector system

3 Tracking & PID systems

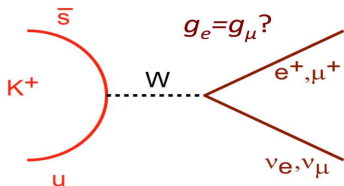
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Lepton universality in K^+ decays

2-body decay of K^+

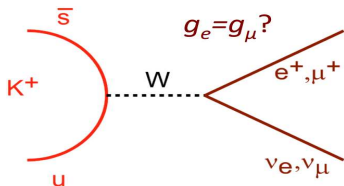
$$\Gamma(K_{l2}) = g_l^2 \left(\frac{G^2}{8\pi} \right) f_K^2 m_K m_l^2 \left[1 - \left(\frac{m_l^2}{m_K^2} \right) \right]^2$$



Lepton universality in K^+ decays

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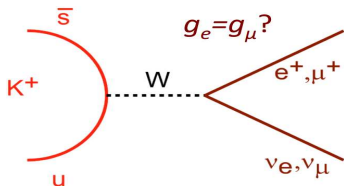
Decay width ratio of electronic (K_{e2}) and muonic ($K_{\mu 2}$) decay modes

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

Lepton universality in K^+ decays

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- Hadronic *form factors* cancel
- Strong *helicity* suppression of electronic channel enhances sensitivity to effects beyond SM
- SM prediction is highly precise: $R_K^{SM} = (2.477 \pm 0.001) \times 10^{-5}$

Other measurements of lepton universality

- Highly precise SM value

$$R_K = (2.477 \pm 0.001) \times 10^{-5} \text{ (with } \delta_r = -0.036), \quad \delta R_K/R_K = 0.04\%$$

V. Cirigliano, I. Rosell, *Phys. Rev. Lett.* 99, 231801 (2007)

- KLOE @ DAΦNE (in-flight decay)

$$R_K = (2.493 \pm 0.025 \pm 0.019) \times 10^{-5}$$

F. Ambrosino et al., *Eur. Phys. J. C* 64, 627 (2009)

- NA62 @ CERN-SPS (in-flight decay)

$$R_K = (2.488 \pm 0.007 \pm 0.007) \times 10^{-5}$$

C. Lazzeroni et al., *PLB* 719, 105 (2013)

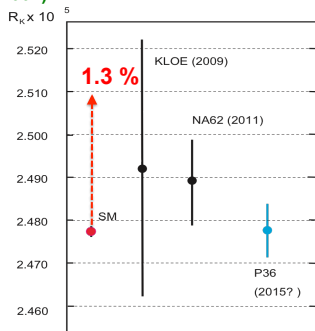
- World average (2012)

$$R_K = (2.488 \pm 0.009) \times 10^{-5}, \quad \delta R_K/R_K = 0.4\%$$

- Systematics:

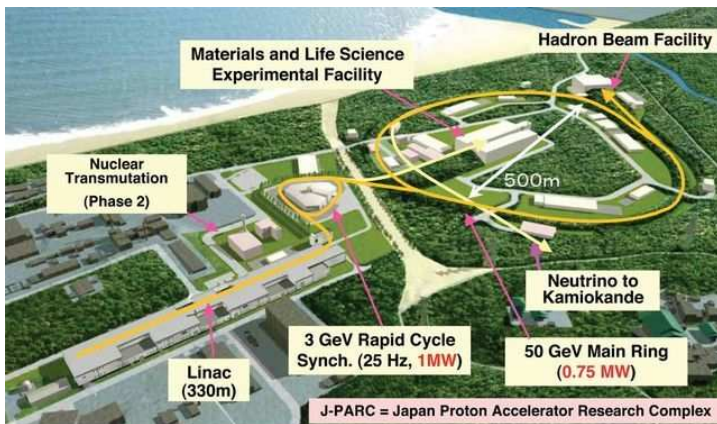
- In-flight-decay experiments: kinematics overlap
- E36 stopped K^+ : detector acceptance and target
- E36 complementary to in-flight experiments

- E36 goal: $\delta R_K/R_K = \pm 0.2\%$ (stat) $\pm 0.15\%$ (syst) [0.25% total]



M. Kohl (ICHEP 2016)

Bird's eye view of J-PARC



Joint Project between KEK and JAEA

Timeline of TREK/E36

TREK: Time Reversal Experiment with Kaons



December 2014

- Installed detector components

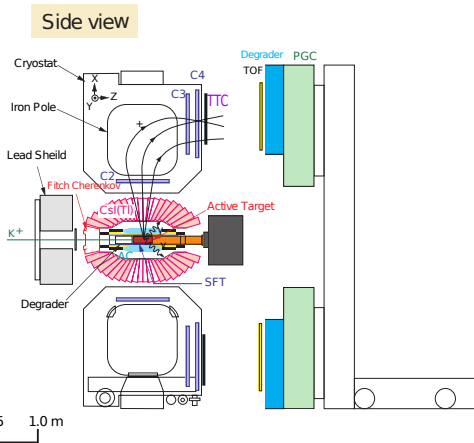
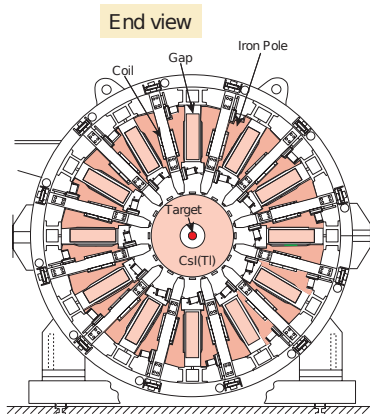
February - June 2015

- Completed installation of C3 & C4
- Cabling
- Detector maintenance

September - December 2015

- Physics run
- Data taking

E36 detector geometry



Stopped K^+ method

K1.1BR beamline
 K^+ stopping target

Momentum measurement

MWPC (C2, C3, C4)
 Spiral fiber tracker (SFT)
 Thin trigger counter (TTC)

Particle ID

TOF
 AC
 PGC

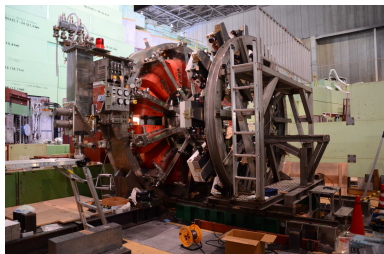
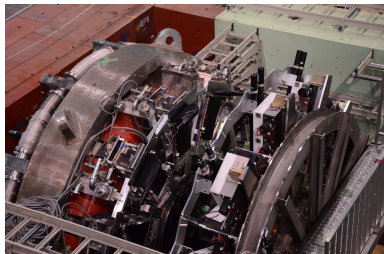
Gamma ray

CsI(Tl)

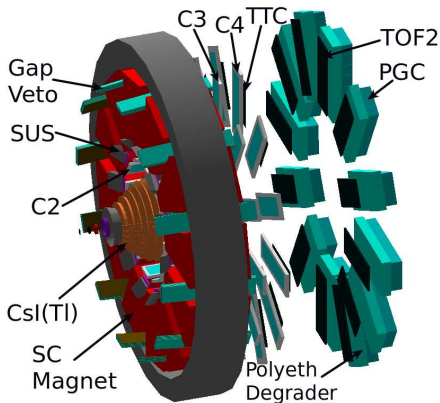
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Geant4 generated geometry

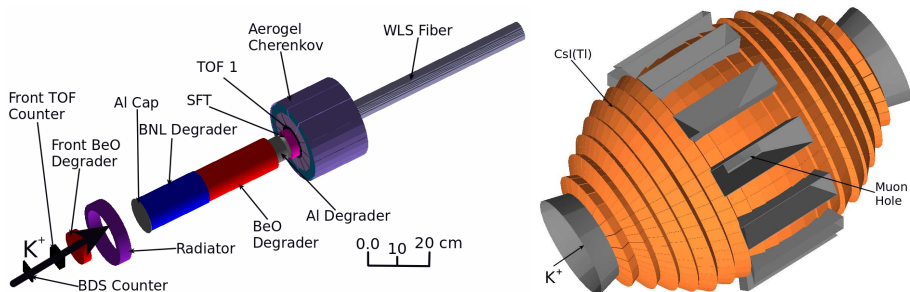


- Detector Assembly



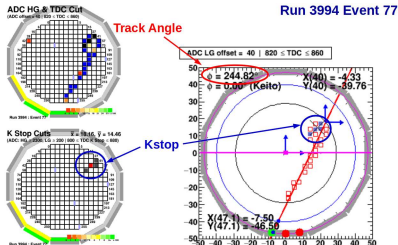
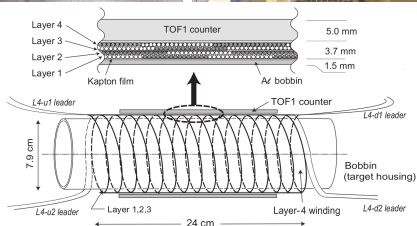
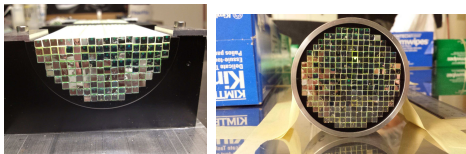
- Geant4 E36 detector

Central Detector



- Central Detector

Target and spiral fiber tracker (SFT)

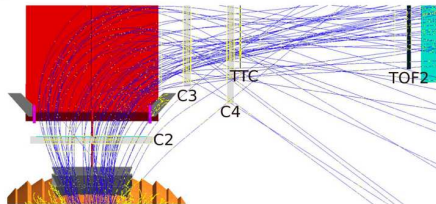
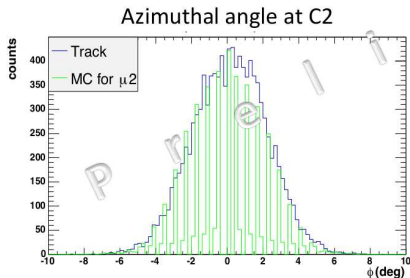
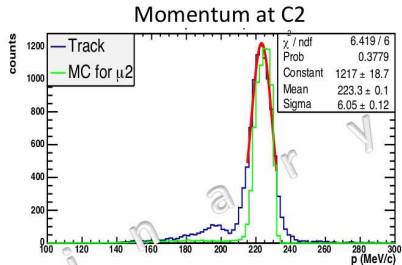
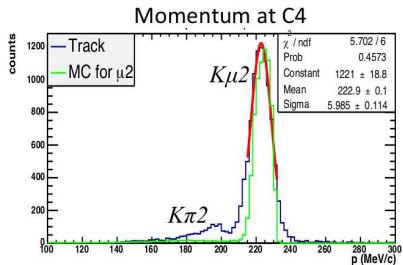


- Determination of K^+ stopping position lepton track length
- Segmented target in conjunction with the SFT yields transverse and longitudinal information

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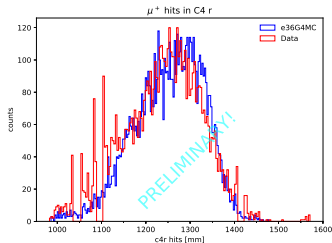
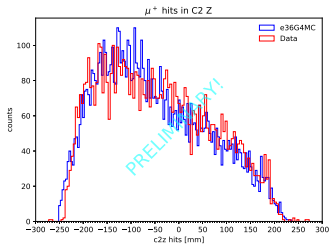
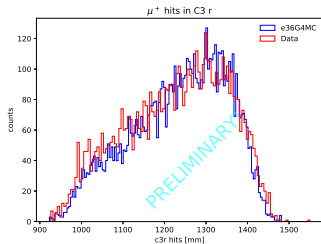
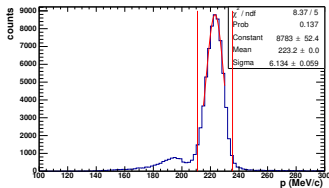
Tracking: momentum reconstruction



Simulated data is from B. Dongwi

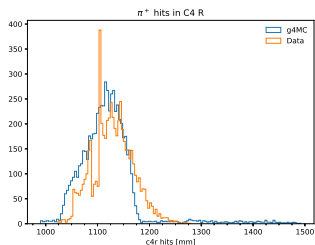
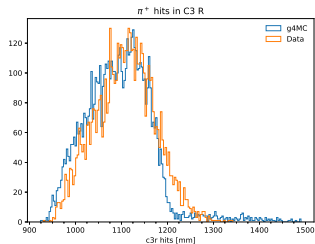
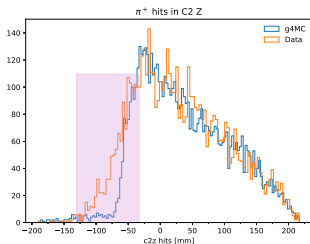
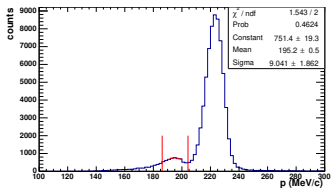
T. Cao (DNP 2017)

$$K^+ \rightarrow \mu^+ \nu_\mu \quad (P_{\mu^+} = 236 \text{ MeV}/c)$$



- Trigger on Target \otimes TOF1 \otimes TTC \otimes TOF2
- $z = 2.5\text{cm}$ and $x = y = 0.0\text{cm}$ $\sigma_z = 8.75\text{cm}$, $\sigma_{x,y} = 0.15\text{cm}$

$$K^+ \rightarrow \pi^+ \pi^0 \quad (P_{\pi^+} = 205 \text{ MeV}/c)$$



● Trigger on Target ⊗ TOF1 ⊗ TTC ⊗ TOF2

● $z = 2.5\text{cm}$ and $x = y = 0.0\text{cm}$
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Particle identification systems

Preliminary PID results

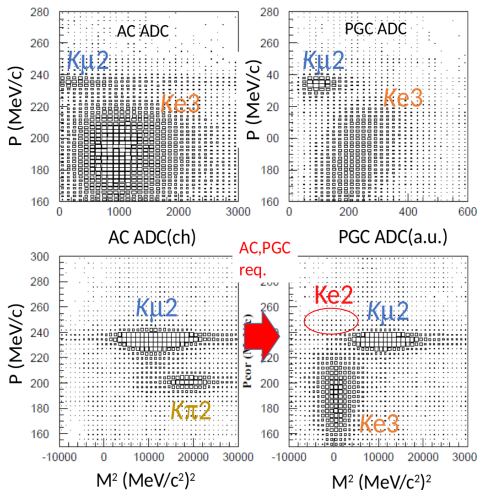
- e^+ are selected by aerogel cherenkov (AC), lead-glass counter (PGC) and TOF detectors
- PID will be performed by combing all three detectors

$$K_{\mu 2}: K^+ \rightarrow \mu^+ \nu_{\mu}$$

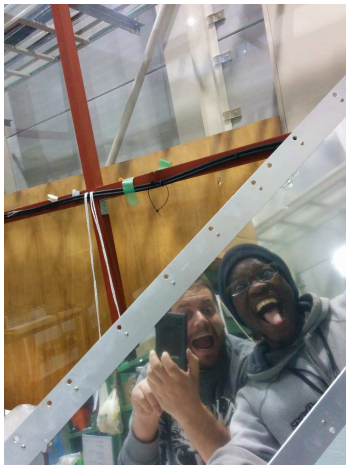
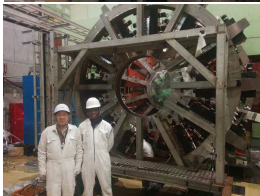
$$K_{\pi 2}: K^+ \rightarrow \pi^+ \pi^0$$

$$K_{e 2}: K^+ \rightarrow e^+ \nu_e$$

$$K_{e 3}: K^+ \rightarrow \pi^0 e^+ \nu_e$$



We are family



#PhysicsWithoutBorders



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Summary and Remarks

- The TREK/E36 experiment has been run and decommissioned
- Data analysis is currently ongoing
- Currently working on improving the energy-loss in Geant4 and tracking packages
- Very good agreement between Geant4 and experimental data for $K_{\mu 2}$ hit distribution
- Hit distribution for $K_{\pi 2}$ are in good agreement but more work is needed to improve this agreement
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Lepton non-universality is the flagship for BSM physics

Collaboration

Approximately 30 collaborators

Spokespeople:

M. Kohl, S. Shimizu

CANADA

University of British Columbia
Department of Physics and Astronomy
TRIUMF

USA

University of South Carolina
Department of Physics and Engineering
Iowa State University
College of Liberal Arts & Sciences
Hampton University
Department of Physics

JAPAN

Osaka University
Department of Physics
Chiba University
Department of Physics
High Energy Accel. Research Organization (KEK)
Institute for Particle and Nuclear Studies

RUSSIA

Russian Academy of Sciences (RAS)
Institute for Nuclear Research (INR)

ありがとうございました
(Thank You)



Back up slides

Possible New Physics that violate $\mu - e$ universality

Proposed NP models

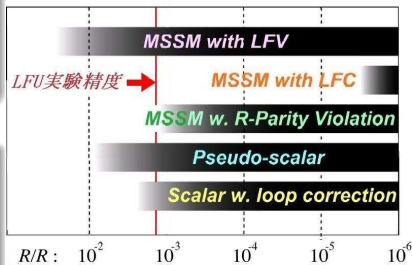
- MSSM with R-parity violation
- Pseudo-scalar interaction
- Scalar with loop Correction
- MSSM with LFV for K_{e2}

SUSY effects

- Charged Higgs H^+ mediated LFV SUSY
→ Large effect but strong constraints from

$$B_s \rightarrow \mu^+ \mu^-$$

J. Girschbach and U. Nierste,
arXiv:1202.4906



Lepton universality violation: ($\mu - \tau$)

Combined measurement of $R(D^*)$

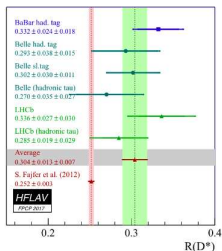
$$R_{D^{(*)}} = \frac{\mathcal{B}(B \rightarrow D^{*} \tau \nu)}{\mathcal{B}(B \rightarrow D^{*} \mu \nu)}$$

- $R(D^*)_{Hadronic} = 0.285 \pm 0.019(stat) \pm 0.025(syst) \pm 0.014(ext)$

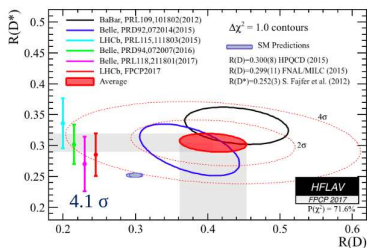
- $R(D^*)_{Muonic} = 0.336 \pm 0.027(stat) \pm 0.030(syst)$

LHCb_{ave}: $R(D^*) = 0.306 \pm 0.027 \rightarrow 2.1\sigma$ above the SM prediction

HFLAV world_{ave}: $R(D^*) = 0.304 \pm 0.015 \rightarrow 3.4\sigma$ above the SM



Lupato (PANIC 2017)



HFLAG average of combined $R(D)$ and $R(D^*)$ is 4.1σ from the SM prediction

Lepton non-universality in the $e - \mu$ sector

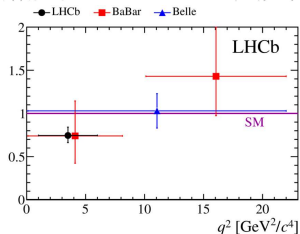
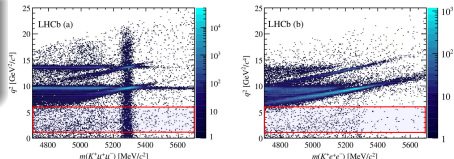
$$R_K[q_{min}^2, q_{max}^2] = \frac{\int_{q_{min}^2}^{q_{max}^2} dq^2 \frac{d\Gamma(B \rightarrow K \mu^+ \mu^-)}{dq^2}}{\int_{q_{min}^2}^{q_{max}^2} dq^2 \frac{d\Gamma(B \rightarrow K e^+ e^-)}{dq^2}}$$

- SM prediction: $R_K^{SM} = 1 + 0(10^{-2})$
- Signal: $1 < q^2 < 6 \text{ GeV}^2$

$$R_K = 0.745_{-0.074}^{+0.090} \pm 0.036 \text{ (sys)}$$

2.6 σ deviation!

$$q^2 = m_{ll}^2$$



Lupato (PANIC 2017)

Lepton non-universality is the flagship for physics beyond the Standard Model