



The TREK Experiment at J-PARC

Precise Measurement of the $K_{e2}/K_{\mu2}$ branching ratio
and the Search for New Physics Beyond the Standard Model

Sébastien Bianchin on behalf of the TREK/E36 Collaboration
(TRIUMF / University of British Columbia)



THE
UNIVERSITY OF
BRITISH
COLUMBIA

Outline

- **TREK program** **TREK = Time Reversal Experiment with Kaons**

E36: Test of Lepton Universality
Search for dark photon
Search for heavy neutrinos

} **Lower Intensity**

E06: Search for Time Reversal Symmetry Violation

- **Physics Motivation**
- **J-PARC Facility & TREK Apparatus**
- **Preliminary Results**
- **Summary & Outlook**



The TREK Program

- **E36 (Lepton Flavor Universality)**

“Measurement of $R_K = \Gamma(K^+ \rightarrow e^+ \nu) / \Gamma(K^+ \rightarrow \mu^+ \nu)$
and a search for dark photons & heavy sterile neutrinos”

Collected data during Fall 2015 30 - 45 kW

- **E06 (TREK)**

“Measurement of the T-violating transverse muon
polarization (P_T) in $K^+ \rightarrow \pi^0 \mu^+ \nu$ decays”

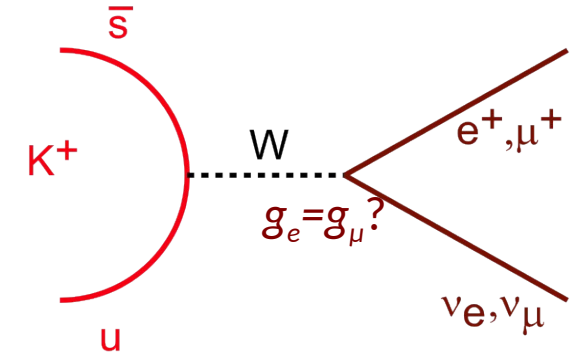
Stage-1 approved (July 2006) 100 - 270 kW

**E06 awaits a new beamline in the Extended Hadron
Hall with higher K^+ intensity**

Lepton Universality in SM for K_{l2}

Standard Model

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



- In the ratio of $\Gamma(K_{e2})$ to $\Gamma(K_{\mu2})$, hadronic form factors are cancelled

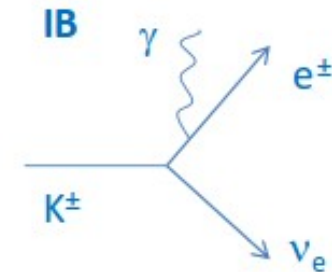
$$\rightarrow R_K^{SM} = \frac{\Gamma(K^+ \rightarrow e^+ \nu)}{\Gamma(K^+ \rightarrow \mu^+ \nu)} = \frac{m_e^2}{m_\mu^2} \left(\frac{m_K^2 - m_e^2}{m_K^2 - m_\mu^2} \right)^2 \underbrace{(1 + \delta_r)}_{\text{radiative corrections}}$$

helicity suppression

- Strong helicity suppression of the electronic channel enhances sensitivity to effects beyond the SM
- Radiative corrections are due to the internal Bremsstrahlung part of the radiative $K \rightarrow e \nu \gamma$ process
- Highly precise SM prediction:

$$R_K^{SM} = (2.477 \pm 0.001) \times 10^{-5} ; \quad \delta R_K / R_K = 0.04\%$$

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



Experimental Status of R_K

- Highly Precise SM value

$$R_K = (2.477 \pm 0.001 \pm 0.007) \times 10^{-5}$$

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

- KLOE @ DAΦNE (in-flight decay) (2009)

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

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

- NA62 @ CERN-SPS (in-flight decay) (2013)

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

[C. Lazzeroni et al., *PLB* 719, 326 (2013)]

- World Average (2013)

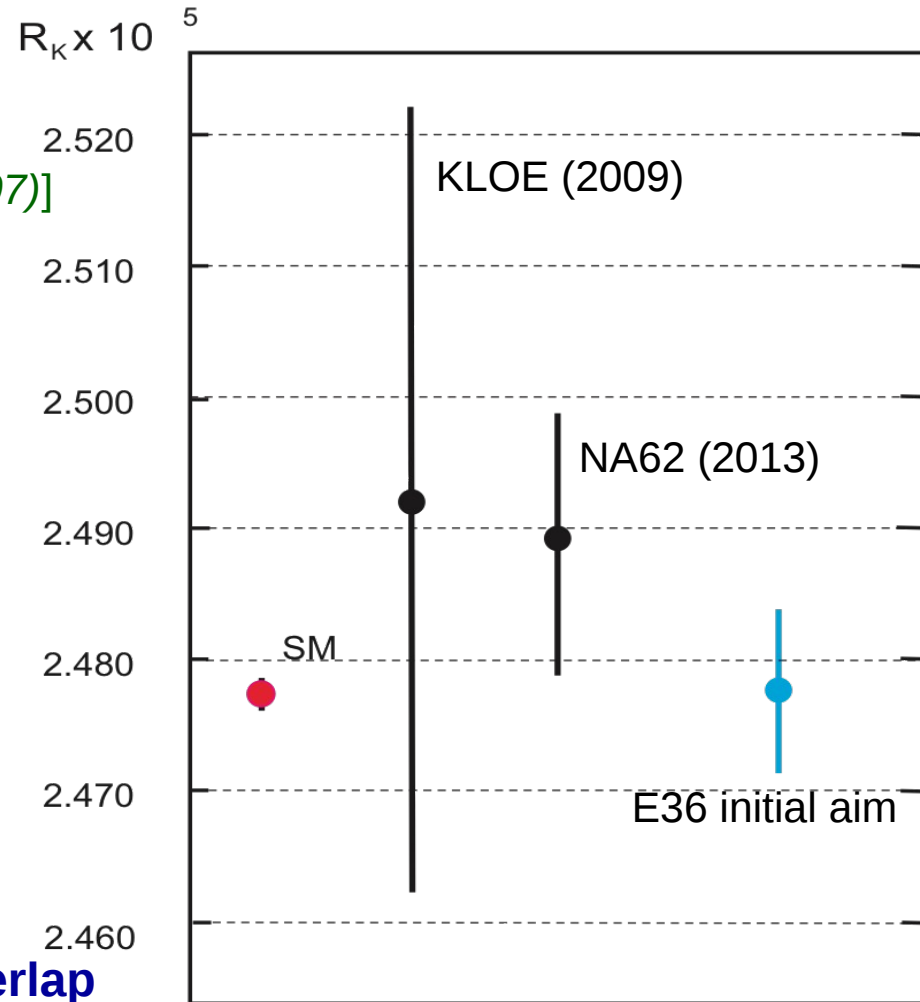
$$R_K = (2.488 \pm 0.01) \times 10^{-5} \quad \Delta R_K / R_K \approx 0.4\%$$

- Different systematics

- In-flight-decay experiments : kinematics overlap
- E36 stopped K^+ decay experiment : detector acceptance and target interactions

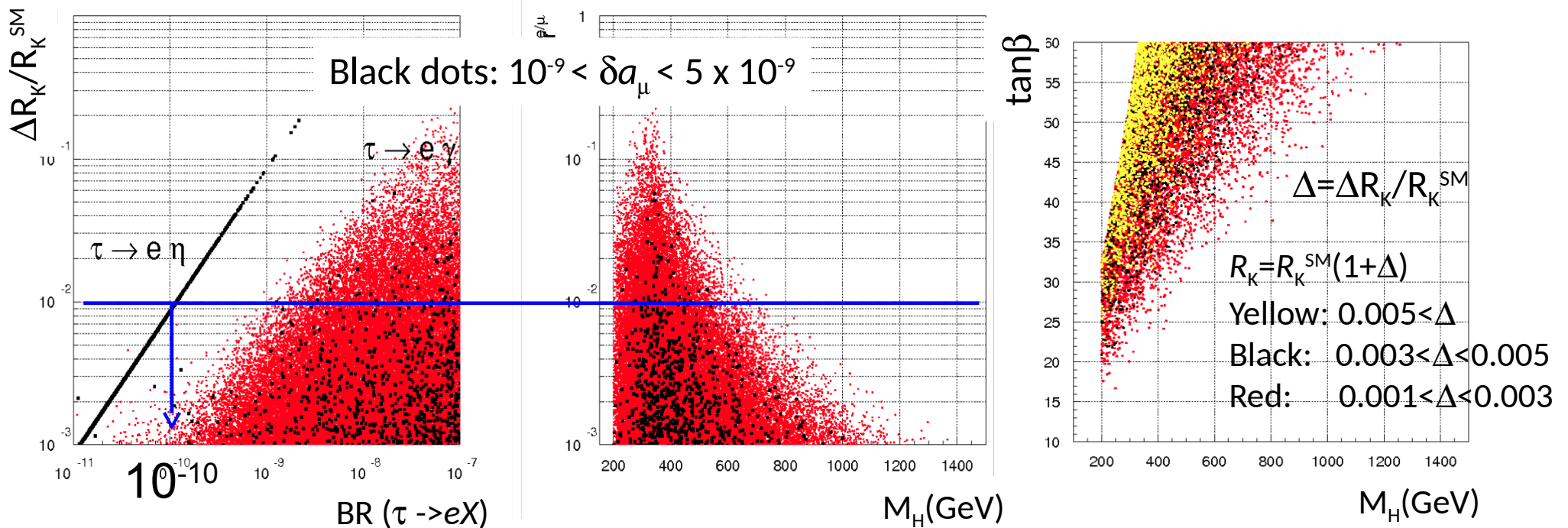
- E36 proposed $\Delta R_K / R_K$

$$\Delta R_K / R_K : \approx \pm 0.20\% \text{ (stat.)} \pm 0.15\% \text{ (syst.)} \quad [0.25\% \text{ total}]$$



Lepton Flavor Violation in SUSY

- LFV effect may be found in ΔR_K
- $\Delta R_K/R_K \approx 1\%$ corresponds to $BR(\tau \rightarrow eX) \leq 10^{-10}$
 - Strong correlation to $BR(\tau \rightarrow e\eta)$
 - Additive to R_K^{SM} (no interference: $R_K > R_K^{SM}$)
- Strong constraint on M_H for large $\tan\beta$ (equal to a_μ)

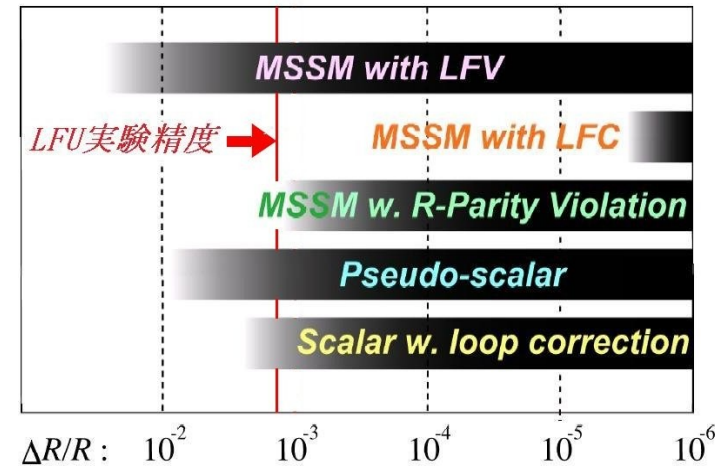


[Masiero, Paradisi and Petronzio; JHEP 11 (2008) 042]

Lepton Universality Violation in K_{l2}

• Possible New Physics

- MSSM with LFV
- MSSM with R-Parity violation
- Pseudo-scalar interaction
- Scalar with loop correction

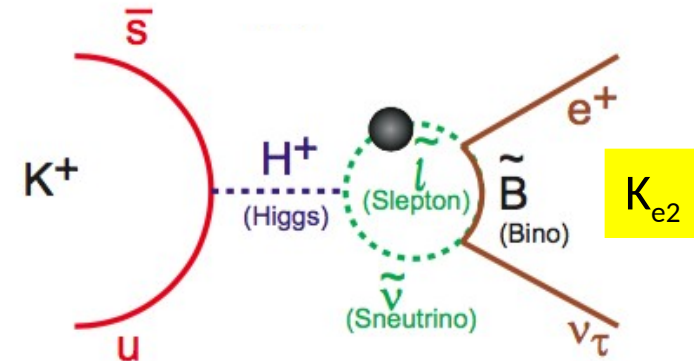


• SUSY with LFV for K_{e2}

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

- Charged Higgs H^+ mediated LFV SUSY
- Large enhancement for m_τ^2 / m_e^2
- A sizable effect up to $\Delta R_K / R_K \sim 1.3\%$ possible

[Masiero, P. Paradisi, & R. Petronzio, *Phys Rev D*74(2006) 011701, *JHEP* 11(2008) 042]
 [J. Girrbach and U. Nierste, *JHEP* 05 (2010) 026; arXiv:1202.4906]



• Neutrino Mixing

- R_K sensitive to neutrino mixing parameters within SM with 4th generation of quarks and leptons or sterile neutrinos

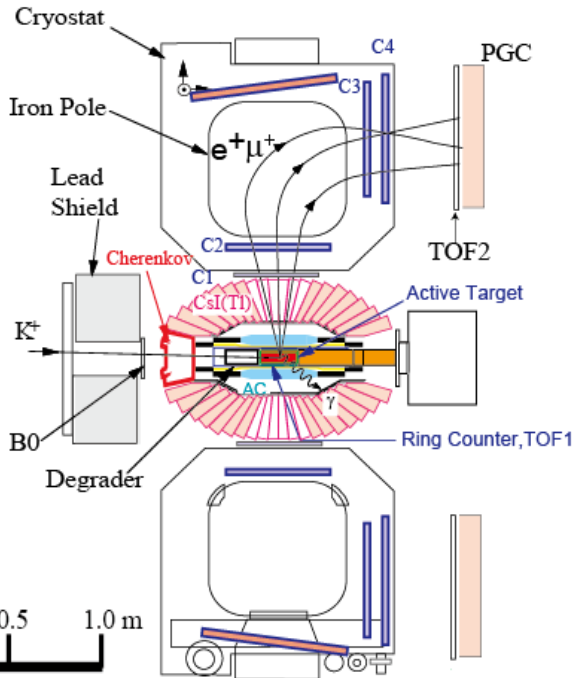
[H. Lacker and A. Menzel, *JHEP* 1007 (2010) 006; A. Abada et al., arXiv: 1211.3052]

J-PARC Facility

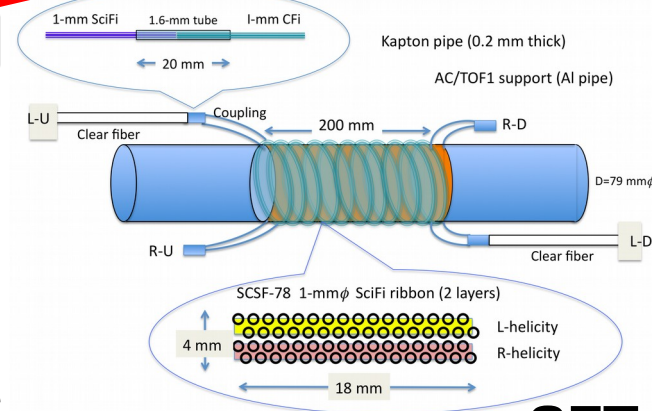
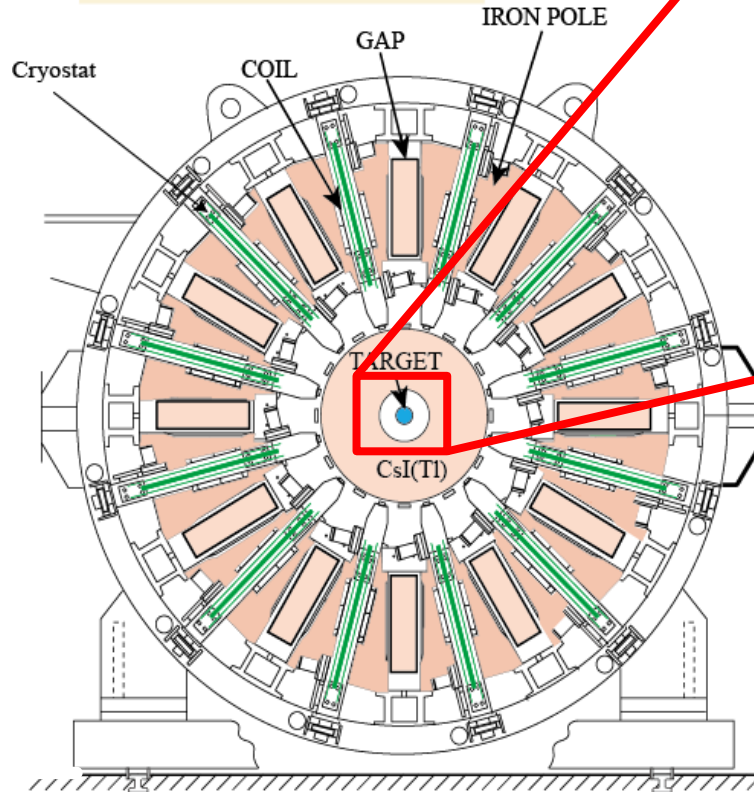


The TREK-E36 Apparatus

Side View



End View



Upgrade of KEK-PS E246 apparatus

SFT

Stopped K Method

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

Tracking

- MWPC (C2, C3, C4)
- Spiral Fiber Tracker (SFT)

PID

- TOF1,2; TTC
- Aerogel Cherenkov (AC)
- Pb glass counter (PGC)

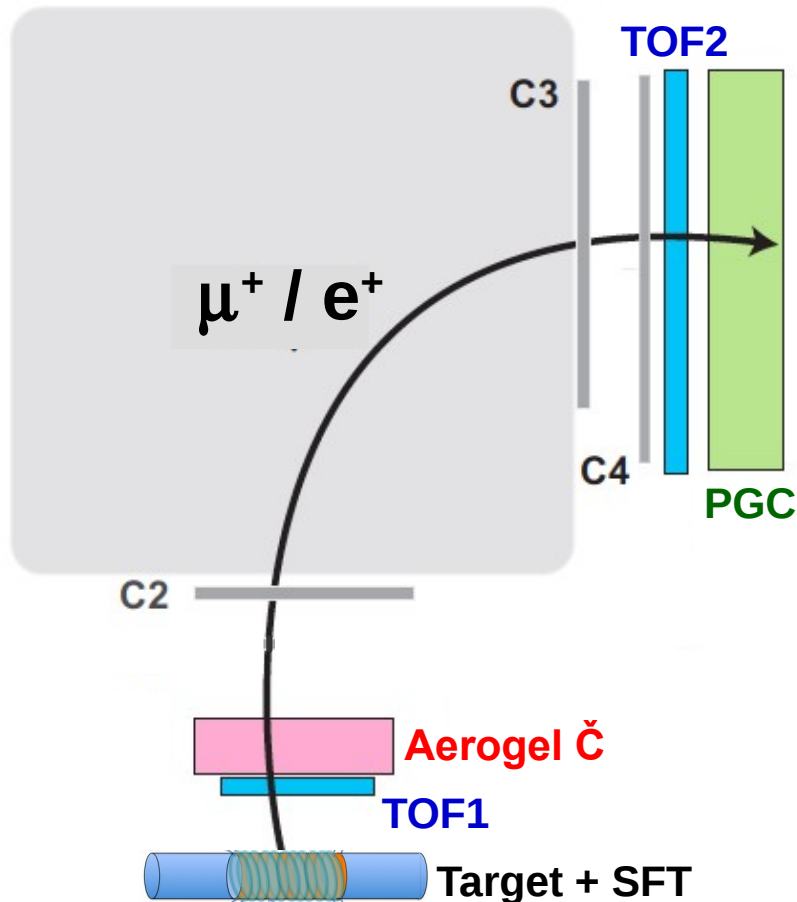
Gamma Ray

- CsI(Tl)
- Gap Veto (GV)

Particle Identification (μ^+ / e^+)

PID done with:

- TOF
- Aerogel Č
- Lead glass (PGC)

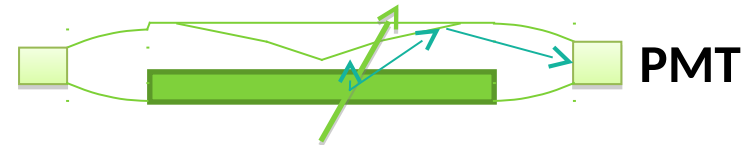


TOF

Flight length	250 cm
Time resolution	<100 ps
Mis-ID probability	7×10^{-4}

Aerogel Č counter

Radiator thickness	4.0 cm
Refraction index	1.08
e^+ efficiency	>98%
Mis-ID probability	3%



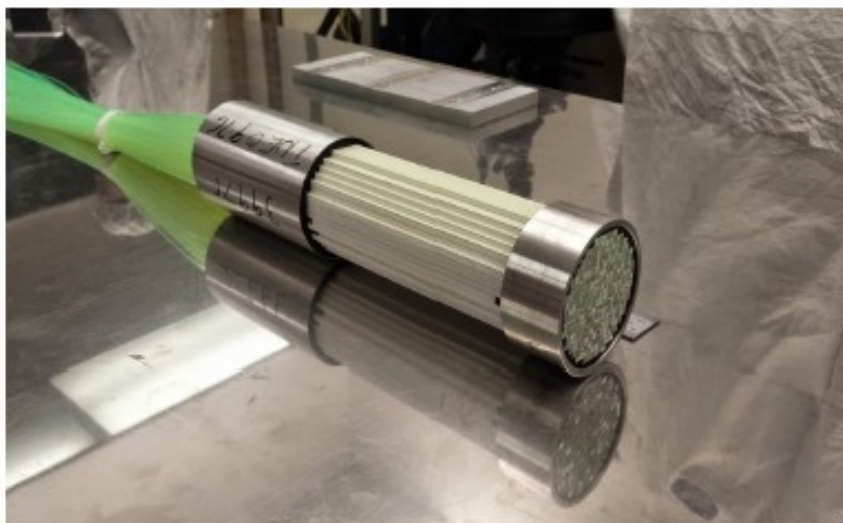
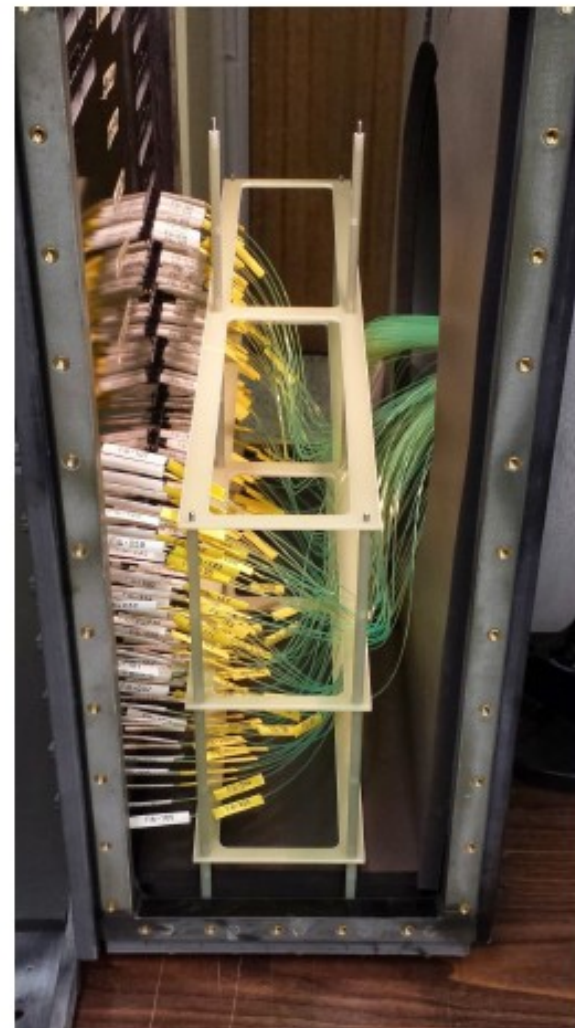
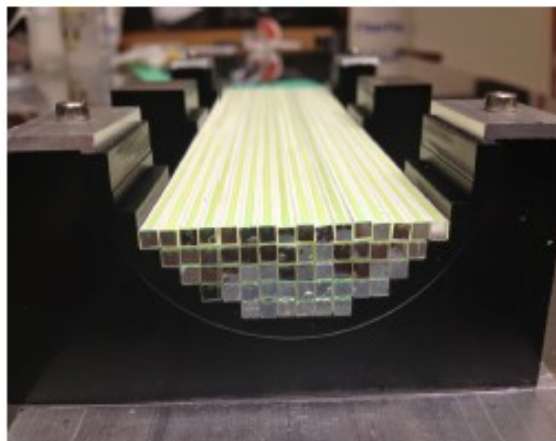
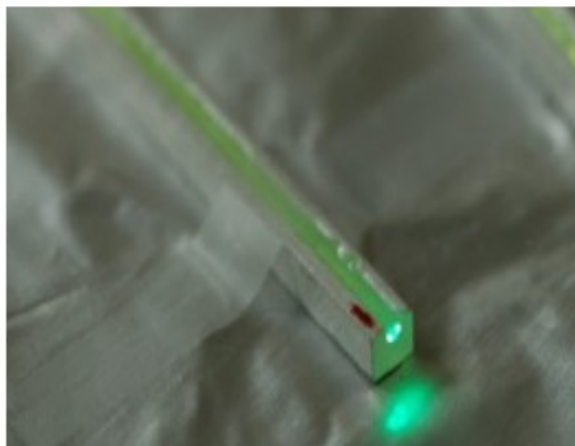
Lead glass (PGC)

Radiation length	1.69 cm
e^+ efficiency	98%
Mis-ID probability	4%

$$P_{\text{mis}} (\text{total}) = P_{\text{mis}} (\text{TOF}) \times P_{\text{mis}} (\text{AČ}) \times P_{\text{mis}} (\text{PGC}) = 8 \times 10^{-7} < O(10^{-6})$$

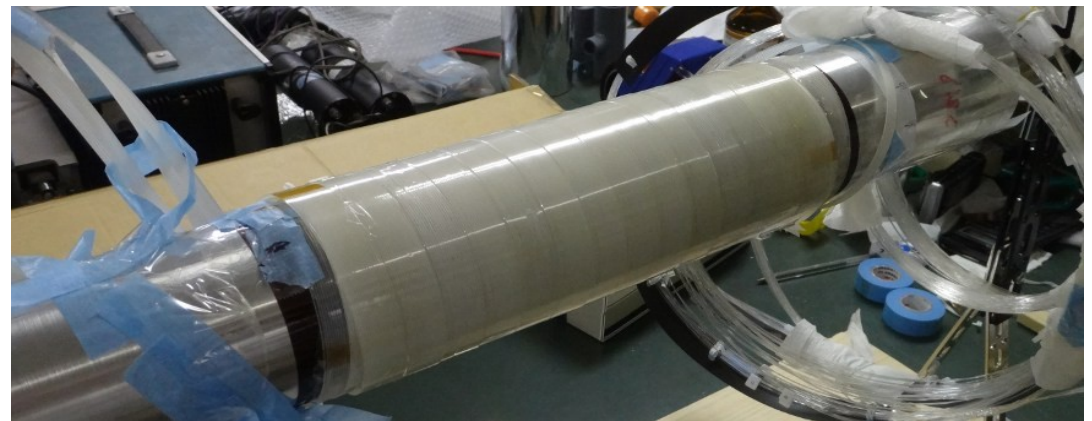
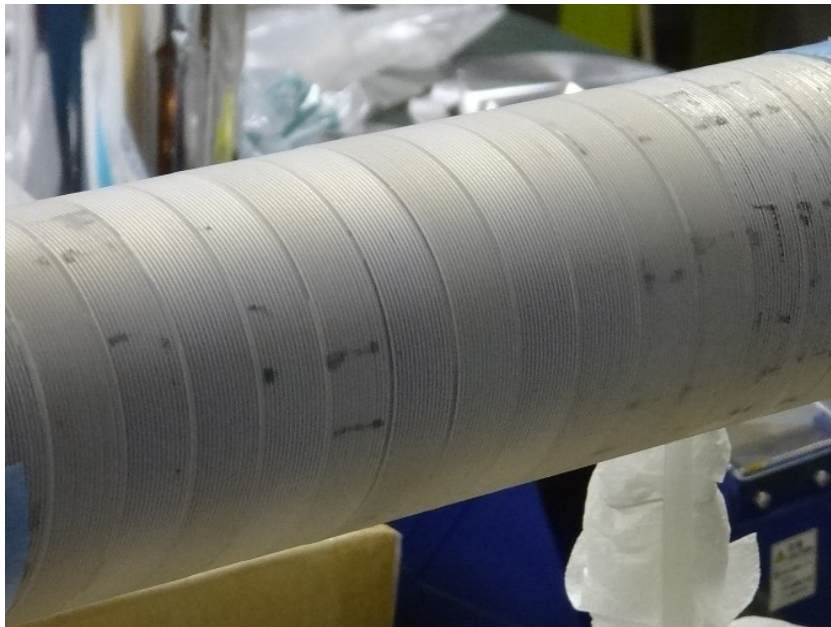
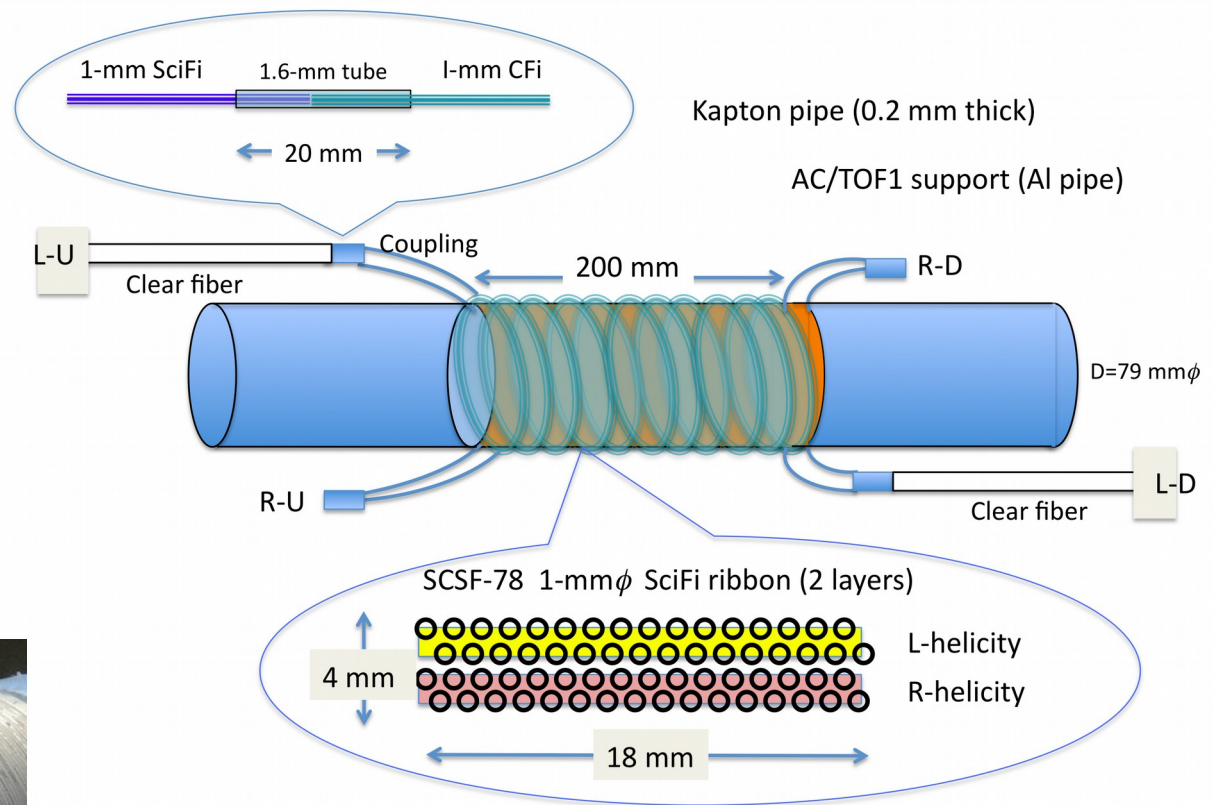
Scintillating Fiber Target

- Built at TRIUMF (delivered to J-PARC in September 2014)
- 256 scintillating fibers (3x3 mm²), WLS fiber in groove
- MPPC readout



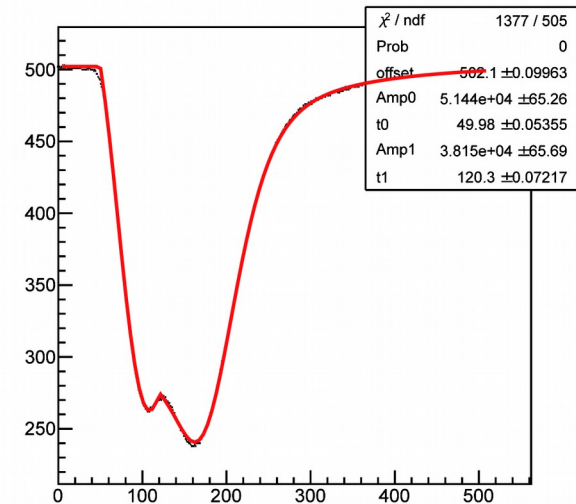
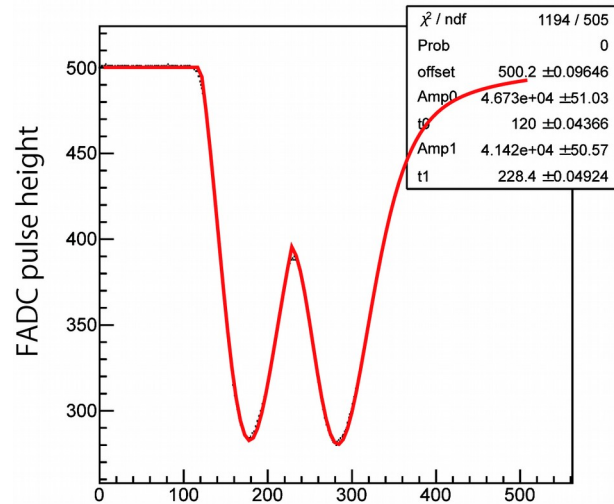
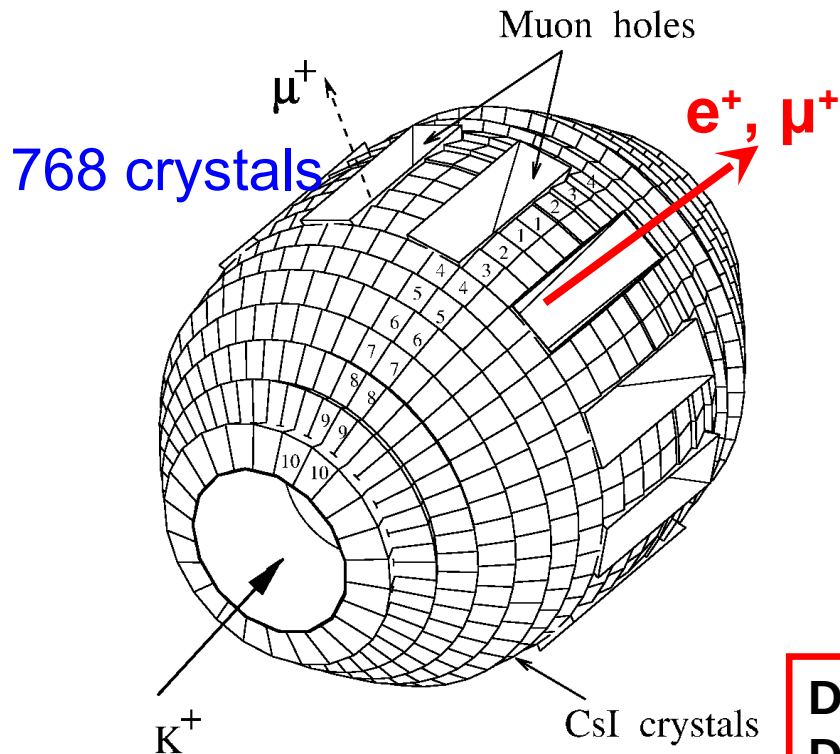
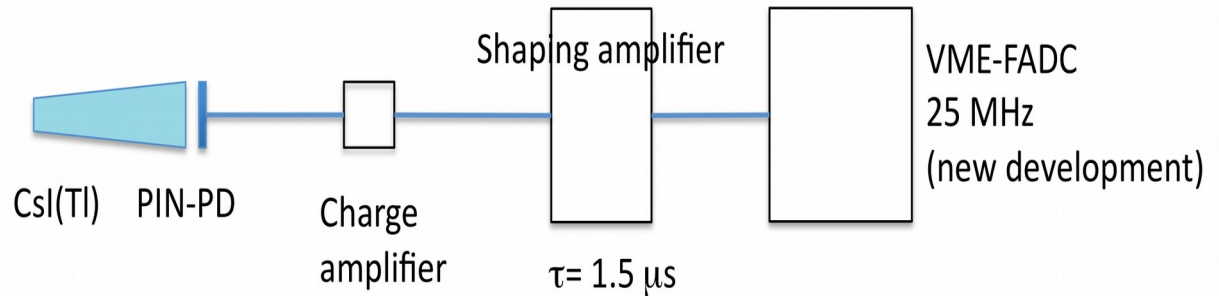
Spiraling Fiber Tracker (SFT)

- Double-layer fibers in 2 helicities wrapped around target bundle for near target vertex
- Using spare MPPCs channels from fiber target



CsI(Tl) Calorimeter

Crystal length 250 mm
Number of crystals 768
Segmentation 7.5°
Coverage ~75%
Readout PIN diodes
Maximum rate ~200 kHz



FADC ch [1ch/40 ns]

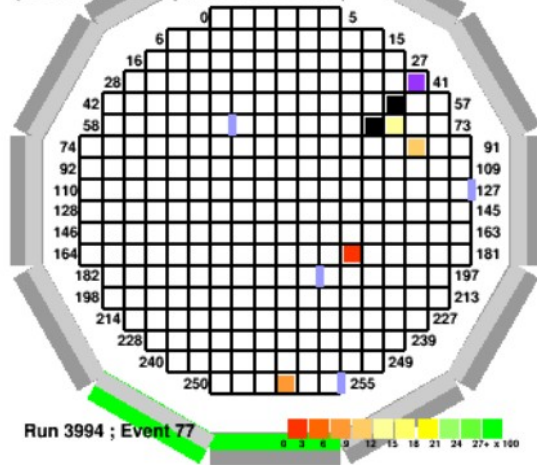
- possible to separate with FADC
- has been implemented successfully

Detection of photons from $K^+ \rightarrow \mu^+(e^+) \nu \gamma$ from IB+SD
Detection of e^+, e^- from A' decay

Target Tracking

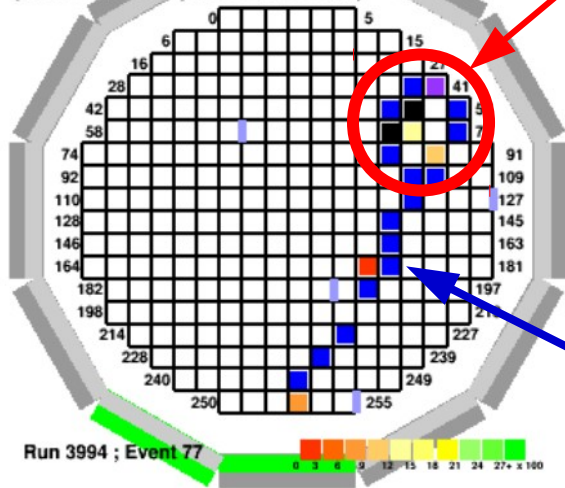
ADC HG & TDC Cut

(ADC offset = 50 | $820 \leq \text{TDC} \leq 860$)



ADC HG & TDC Cut

(ADC offset = 50 | $820 \leq \text{TDC} \leq 860$)



K-stop

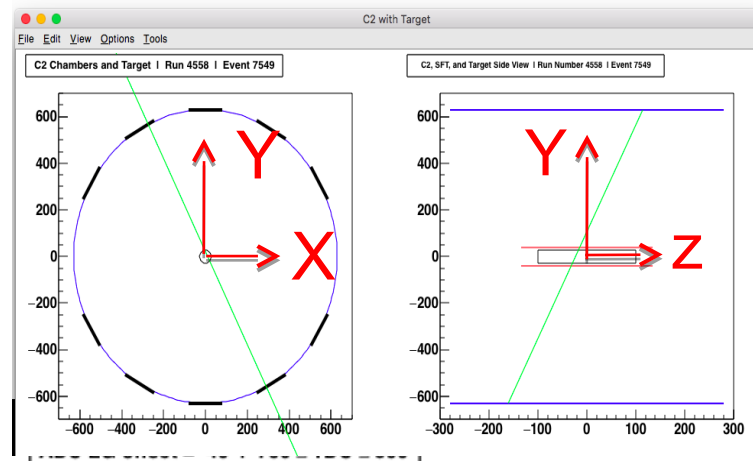
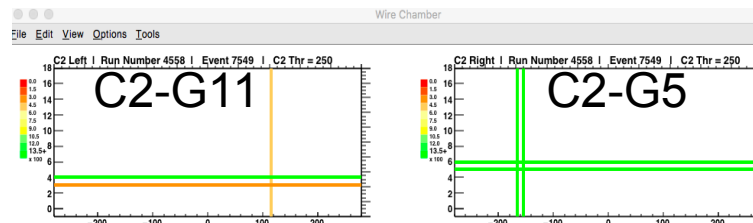
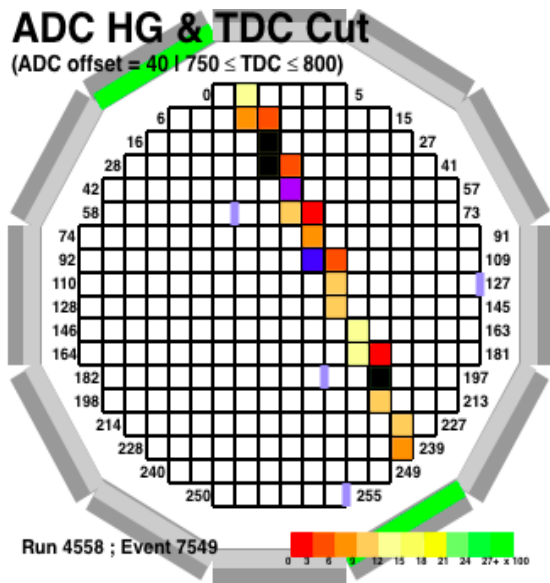
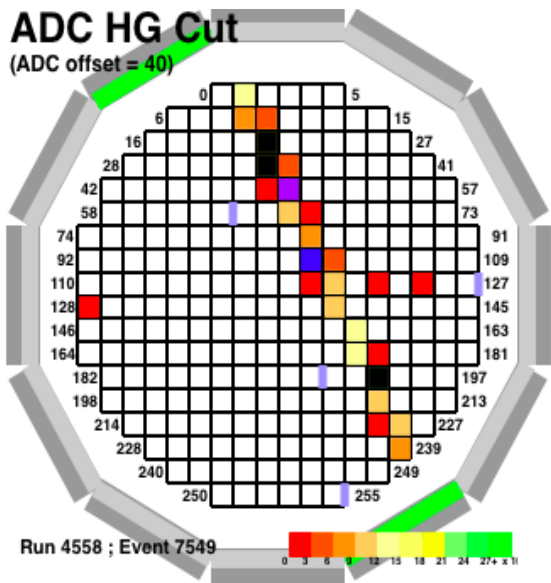
Target hit pattern of a typical good event

Blue fibers with only LG signal

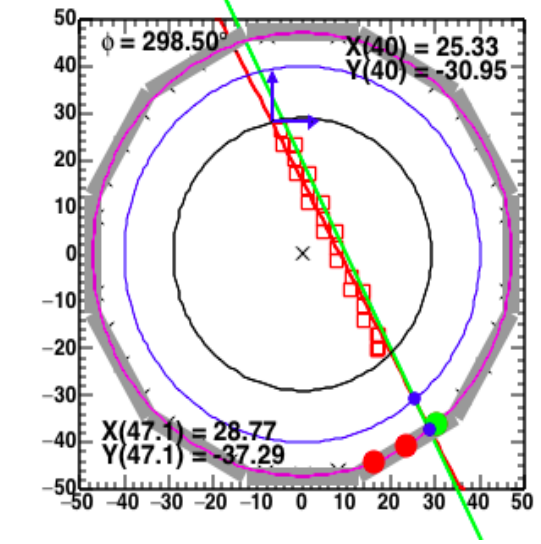
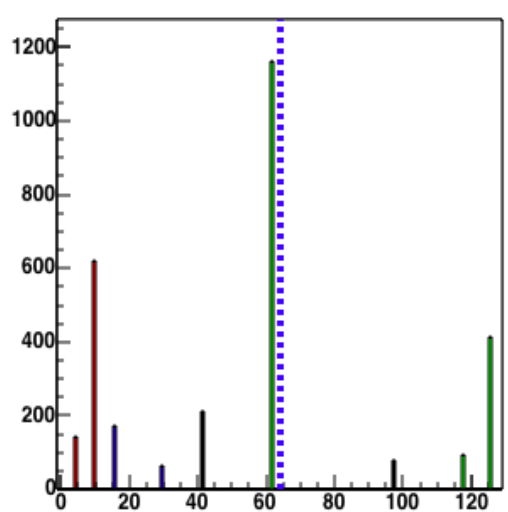
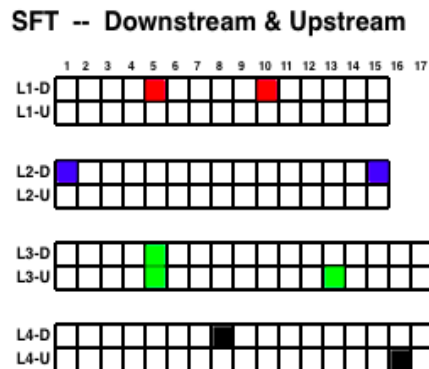
Event 77

- Determination of K^+ stopping point and lepton depth inside the target
- Measurement of lepton emission azimuthal angle to determine SFT-Z
- Innermost element for 5-point tracking (intersection point of track and K^+ cluster)
- Inclusion of **LG ADC** completes the target track (when HG signal is missing)

— Tracking Analysis (Cosmic Rays & SFT) —

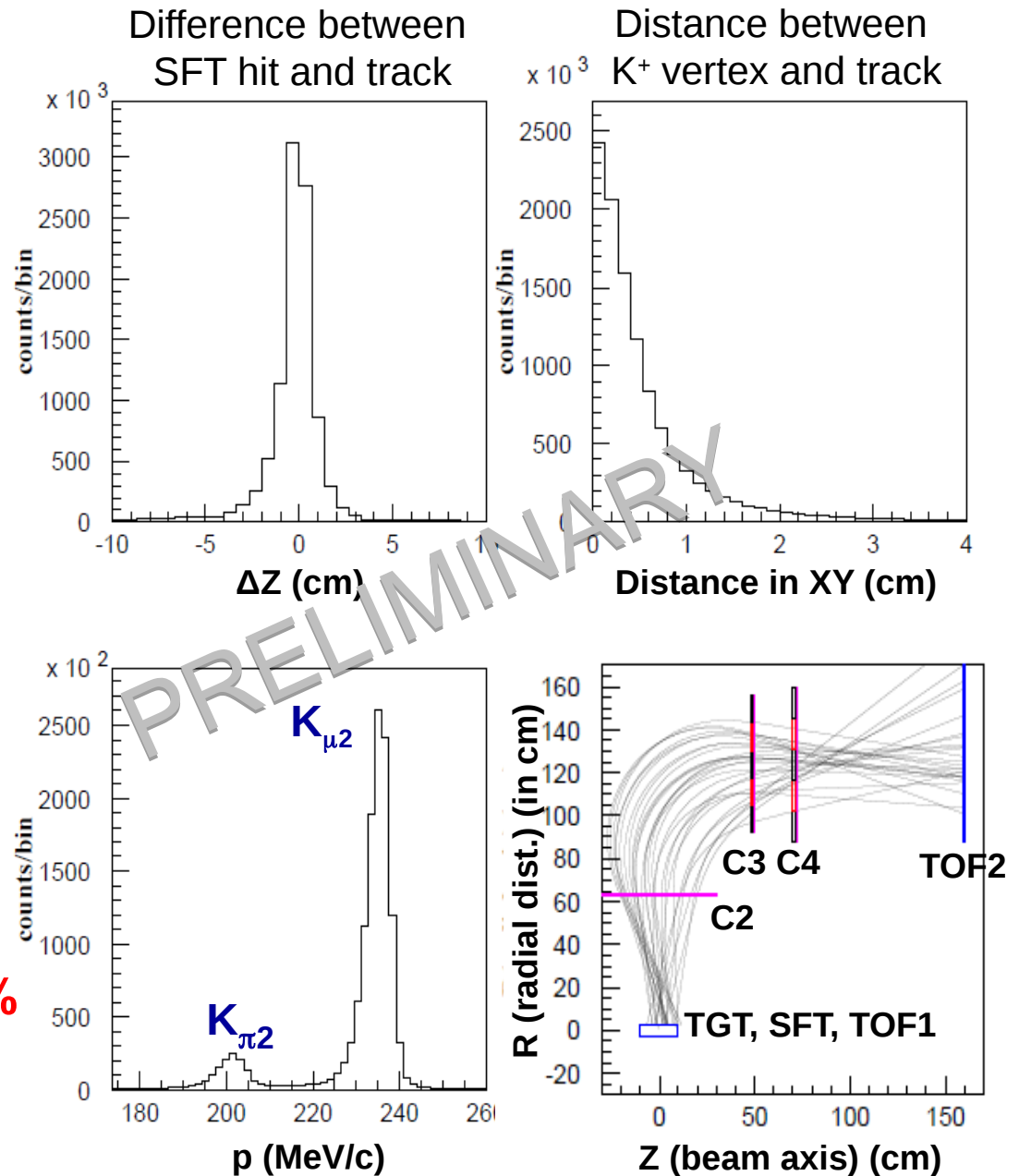


(ADC offset = 30) | (730 < TDC < 860) -- Run 4558 (Event 7549)



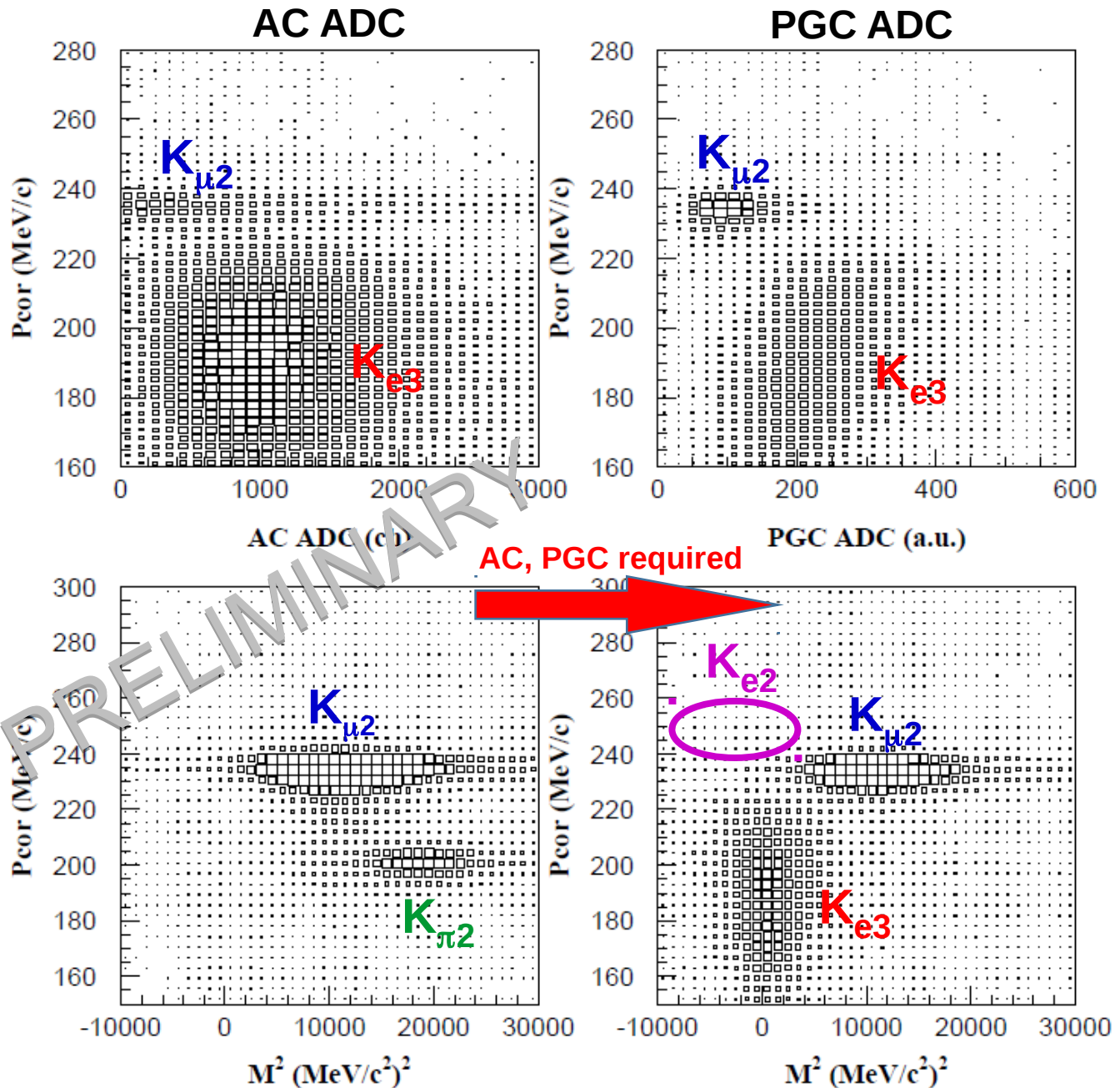
Momentum Analysis

- The charged particle momentum is currently determined by 4 point tracking (C2, C3, C4 MWPCs and target-xy)
- Events are selected by requiring track consistency with the target, SFT and TOF1 - TOF2 gap
- The tracking performance will be improved by introducing the 5 point tracking (C2, C3, C4, MWPCs, target, and SFT-Z)
- Monochromatic peaks due to $K_{\mu 2}$ and $K_{\pi 2}$ are clearly seen
- The momentum resolution $\sigma \sim 1.4\%$ will be improved to 1% by optimizing the target energy loss correction



Particle Identification

- Positrons are selected by AC, PGC and TOF
- PID performance by combining the three detectors is now being optimized
- Suppression of muon mis-identification below $O(10^{-8})$ level achievable with refined analysis
- TOF time walk correction has not yet been applied
- Refined analysis of PID performance in progress



The TREK E36/E06 Collaboration

~30 collaborators

Spokesperson:
S. Shimizu

CANADA

University of British Columbia

Department of Physics and Astronomy

TRIUMF

USA

University of South Carolina

Department of Physics and Astronomy

University of Iowa

Department of Physics

Hampton University

Department of Physics

JAPAN

Osaka University

Department of Physics

Chiba University

Department of Physics

**High Energy Accelerator Research
Organization (KEK)**

Institute of Particle and Nuclear Studies

RUSSIA

Russian Academy of Sciences (RAS)

Institute for Nuclear Research (INR)

Summary and Outlook

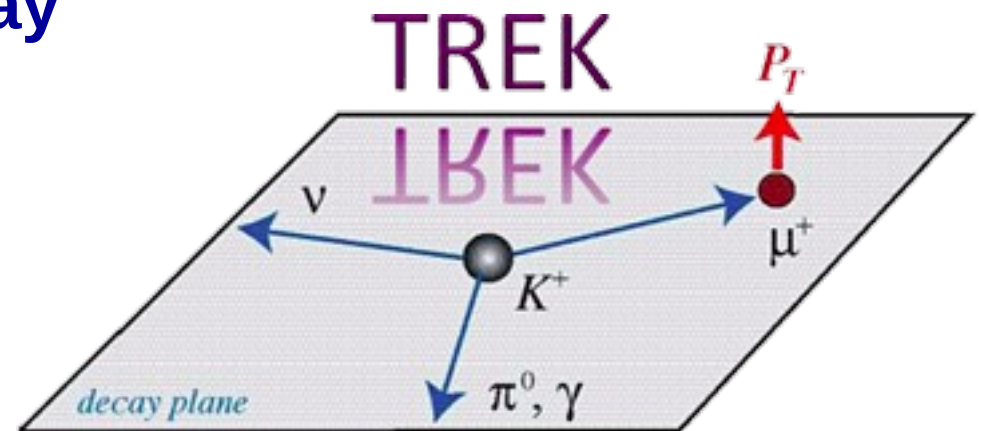
The TREK E36 Collaboration has completed a Lepton Universality Experiment at J-PARC

- $K_{e2}/K_{\mu2}$ ratio measurement to test lepton universality with the best sensitivity available using stopped kaons
- Search for dark photon / light boson
- Analysis currently in progress

Calibration, CsI(Tl), PID, momentum and TOF measurements

NEXT Measurement of the T-violating transverse muon polarization in $K_{\mu3}$ decay

- E06 experiment @ J-PARC (~202x)
- Requires Hadron Hall extension



THANK YOU!