Progress Report
to the
4th J-PARC PAC Meeting

J-PARC E06 (TREK) Experiment

Measurement of T-violating Transverse Muon Polarization in $K \to \pi^0 \mu^+ \nu$ Decays

E06 (TREK) Collaboration*

December 21, 2007

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Contents

1 Introduction

In this note we report on the status of the E06 (TREK) experiment presenting the recent progress in the preparation since the last PAC meeting. In its minutes, PAC made advice and also expressed a few concerns regarding the breadline installation and the high rate performances of detector elements. The minutes said:

"While the E206 (TREK) collaboration has made significant progress from the stage-1 proposal towards the measurement, the PAC still has several concerns related the radiation hardness of the new detector elements due to the large background rate and to the high rate capability of the detector elements. The PAC is also concerned that there are several potential conflicts and interferences between the K0 breadline and K1.1-BR breadline design, as mentioned in the FIFC report. The discussion on the stage-2 recommendation will be made after we hear from the IPNS/J-PARC management on the realistic plan of the beam line installation as discussed more in section 6 of these minutes. The PAC strongly recommends that the IPNS/J-PARC management should develop a workable plan and solution for the installation of both beamlines." The PAC recommended us at the same time: *"The PAC encourages the E06 (TREK) collaboration to establish a conditional MOU between their foreign collaborating institutes and IPNS/J-PARC management for contribution, funding, and scheduling profile based on the current scenario of J-PARC operations funding profile."*

We will answer to these points in this report. Concerning the issue of beamline installation, however, we, the experimental group, cannot do anything but to wait for a workable plan to be established by the IPNS/J-PARC management, and to request again that the K1.1-BR line is installed in a timely manner not missing the timing of installation of the front-end magnets due to radiation accumulation after the start of the T1 target operation. Meanwhile in these 6 months, we deepened the beam optics design also responding to the comments made by the FIFC reviewer Dr. P. Pile. Regarding the recommendation to push forward the project in the approval status of stage 1 by exchanging MOUs with foreign institutions, it is also relying on the policy of IPNS/J-PARC although we are doing our best efforts to put the TREK experiment on a firmer international collaboration basis. We will present the current status. Besides the responses to the PAC comments we report on the important issue concerning the experiment funding.

In the following we describe:

(1) Further studies of high-rate performance of detector elements and radiation damage effects. We understood that the question was raised primarily for:

   - Target fiber readout with MPPC,
   - C0 GEM detector sitting innermost, and
   - APD readout scheme of CsI(Tl).

(2) Further study of the K1.1BR beam optics

(3) Efforts for funding and for establishment of the international cooperation

At the end we would like to ask PAC to consider the stage-2 approval for this experiment.

2 High rate performance of the detector elements

2.1 Target fiber readout

2.1.1 Radiation hardness of MPPC

To the previous PAC meeting as well as to FIFC [1] we showed our consideration to apply a Geiger-mode avalanche photo-diode (MPPC) to the target scintillating fiber readout replacing the current PMT readout on the occasion to reconstruct the whole target assembly with finer segmentation. The adoption of MPPC would enable a compact assembly which is essential to realize a high-precision experiment. We presented a very preliminary basic test result of MPPC readout of a 3×3 mm scintillating fiber directly. At the time of the report submission to the previous PAC, however, the radiation hardness of this device was not yet exactly known. Hence, we mentioned the backup option of using multi-anode PMTs, and wanted to wait for the results of a proton beam irradiation test at RCNP. (In this test experiment three TREK members took part in.) This policy was endorsed by FIFC.

Meanwhile, the data of the proton beam irradiation experiment became available. The performance of MPPC (Hamamatsu S10362-11-050C) after the irradiation of 2.8 Gy, 5.5 Gy and 8.0 Gy with lower beam current of 3.0×10^4 protons/mm^2/s, and of 21 Gy, and 42 Gy with higher current of 2.3×10^5 protons/mm^2/s was investigated by looking at the photon spectrum and the leakage current [2]. The spectra are shown in Fig. 1. What was observed was the increase of the leakage current with the increase of the integrated dose, and its non-recovery during the time range of a few hours. It turned out that MPPC could not show the normal spectrum at the integrated dose of 21 Gy suggesting the breakdown of the MPPC function. Up to the dose value of 8.0 Gy no significant gain drop was observed at the nominal operation voltage. We regard this dose as the safe tolerance against the hadron beam exposure. This dose just calculated from the beam flux and it corresponds to the time-integrated flux density of 5.4×10^7/mm^2 penetrating an MPPC. Another radiation damage study by using a neutron beam (T.Matsumura *et al.* [3]) found also a drastic change of leakage current behaviour indicating the incapability of photon counting at even lower time-integrated fluence of 10^5/mm^2.

2.1.2 Estimate of beam halo

We have studied with GEANT4 MC simulations the downstream particle flux generated by the kaon beam and the contaminant pions in the beam [4]. For this purpose we generated 2×10^6 kaon as well as pion rays at 800 MeV/c and tracked them through the degrader and target assembly. As the downstream particles, $K^+, \pi^+, \mu^+, e^\pm, n$, and p were detected. Fig. 2 and 3 show, as typical examples, the K^+ and π^+ distributions (spatial and momentum *etc.*) with the largest contributions, Tables 1 and 2 give the radial distribution of all the downstream fluxes in the plane which is located 80 cm downstream of the front face of the target, namely 70 cm downstream of the setup center, in the case of K^+ incident beam and π^+ incident beam, respectively, for the nominal operation condition of the accelerator in Phase 1 (30 GeV and 9μs) with the average K^+ intensity of 2.1×10^6/s. One can see that the flux at small radii (7.5 and 12.5 cm) is larger for the pion beam than it is for the kaon beam. The total flux density is about 5 Hz/mm^2 assuming a π^+/K^+ ratio of 1.0[1] which

[1] The beam optics simulation predicts 0.6, but we take 1.0 for safety.

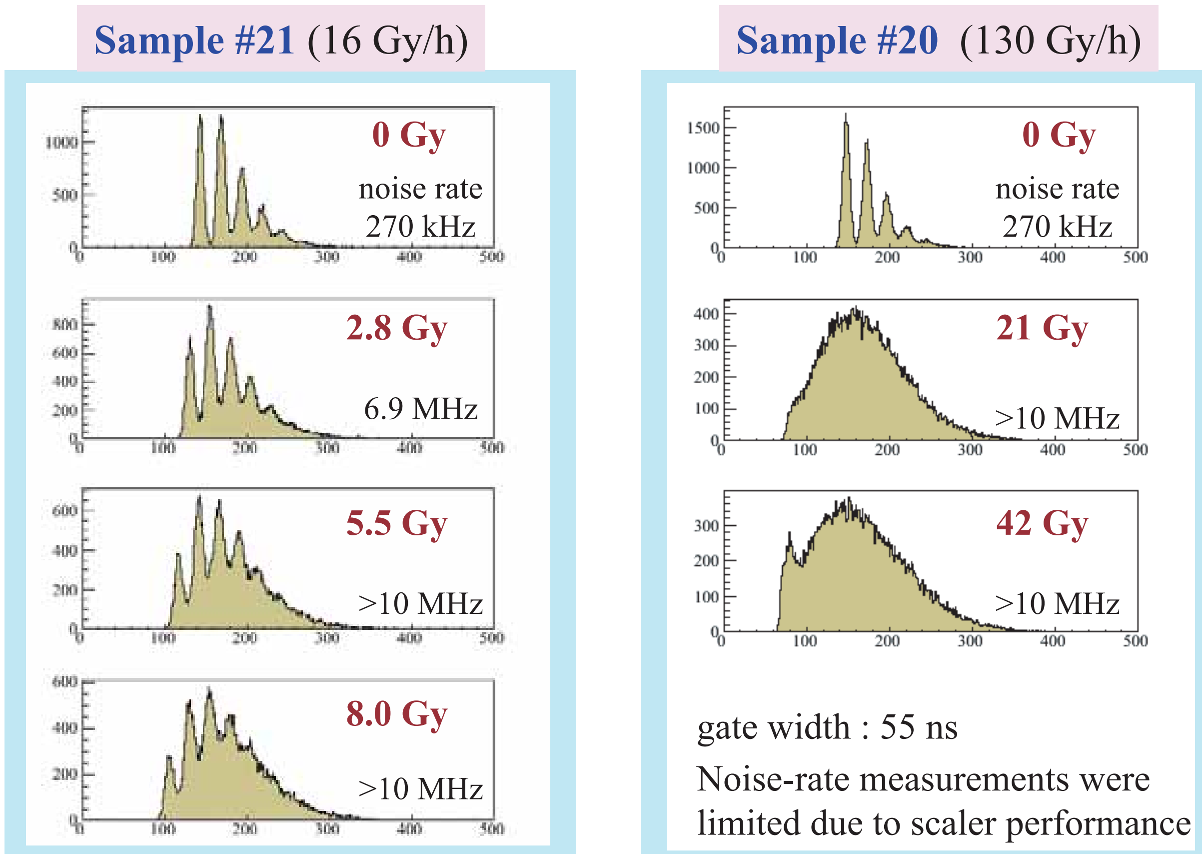

Figure 1: ADC distributions of MPPC (Hamamatsu S10362-11-050C) after irradiating with a 53.3-MeV proton beam at RCNP, Osaka University. Measurements were done for several integrated dose with lower beam intensity for Sample#21 and higher beam intensity for Sample #20. It was found that the leakage current after irradiation depended only on the total accumulated dose. As seen, the photon counting capability is lost due to baseline shifts and noise pile-up certainly at 21 Gy. (From Ref.[2])

Table 1: Radial distribution of various particle fluxes at $z = 80$ cm downstream of the target face for 800 MeV/c incident K^+/π^+ beams. The total flux density in the bottom line is the sum of K^+ and π^+ beam contributions assuming a K^+/π^+ ratio of 1.0.

Radius (cm)	7.5	12.5	20.0	30.0	40.0
K^+ (kHz/mm)	0.30/-	1.40/-	1.90/-	1.40/-	1.00/-
π^+ (kHz/mm)	0.08/3,50	0.16/2.10	0.30/1.80	0.43/1.80	0.45/2.00
μ^+ (kHz/mm)	0.25/1.20	0.55/0.75	0.73/0.20	0.90/0.10	1.00/0.10
n (kHz/mm)	0.08/0.15	0.15/0.25	0.30/0.47	0.46/0.73	0.70/1.10
e^- (kHz/mm)	0.09/0.19	0.21/0.28	0.34/0.43	0.37/0.63	0.40/0.80
p (kHz/mm)	- /0.07	- /0.10	0.04/0.18	0.10/0.28	0.25/0.39
e^+ (kHz/mm)	0.04/0.04	0.08/0.07	0.14/0.14	0.18/0.25	0.20/0.37
Total (kHz/mm)	0.84/5.15	2.55/3.55	3.75/3.22	3.84/3.79	4.00/4.76
Flux density (Hz/mm^2)	0.71/4.37	1.30/1.81	1.20/1.03	0.81/0.80	0.64/0.76
Total flux density (Hz/mm^2)	5.08	3.11	2.24	1.61	1.40

would imply about 7×10^7 particles/mm^2 after 1 year running time, although, if we move out to $r = 40$ cm then the total particle flux density is $\sim$1.5 Hz/mm^2 which leads to a total particle flux of $\sim 2\times 10^7$ particles/mm^2 in a 1 year run. Considering the tolerance value of several times 10^7, we have become worried about using the MPPCs putting them a few 10 cm off the downstream beam axis for our experiment which might run more than one year, in contradiction to our original idea presented to FIFC.

2.1.3 Current choice for the readout elements

We might now want to resort to using multi-anode PMTs such as the Hamamatsu H8711-10. (In E246 a single 1/2" PMT was used for each fiber.) We were initially quite worried about the use of such tubes for a high rate beam counter but the COMPASS experiment at CERN had shown that it is possible to operate such tubes with a chain current up to $\sim$100 μA using a booster HV supply for the intermediate dinode [5]. Of course we are watching other radiation damage studies of MPPC before the final decision. We will follow these very closely and also carry out our damage tests using a pion beam at TRIUMF.

2.2 C0 GEM chamber

2.2.1 GEM prototype beam test

As was already reported to the previous PAC meeting, the MIT team in the TREK collaboration conducted a beam test of triple GEM planer chambers at the Meson Test Beam Facility at FNAL using the Main Injector beam. A high-intensity run was also carried out to check the limit. The results of this test experiment is now available for the estimate of the high-rate performance and beam background hardness of the TREK C0 cylindrical GEM chamber which is placed surrounding the target. A schematic structural view of the detector is shown in Fig.4 and the current design parameters are summarized in Table 2. Since the inner radius is so close to the beam axis, it was reasonable that PAC had a concern

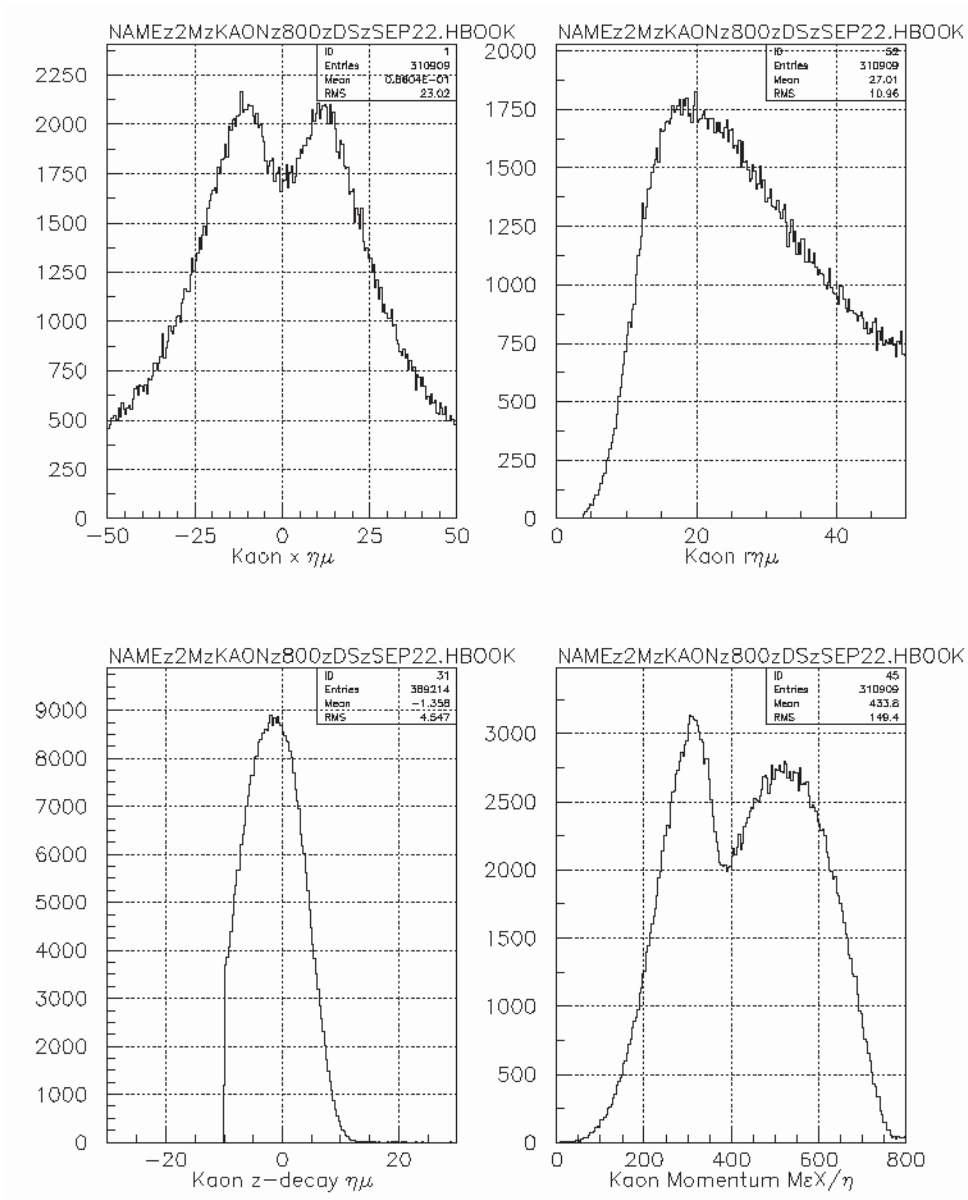

Figure 2: K^+ beam distributions at the 800 MeV/c incident K^+ beam. (a: upper-left) x/cm distribution at $z = 50$ cm; (b: upper-right) r/cm distribution also at $z = 50$ cm; (c: lower-lest) decay point z/cm distribution; (d: lower-right) momentum/MeV/c distribution at $z = 50$ cm. Incident K^+s of 2×10^6 were generated.

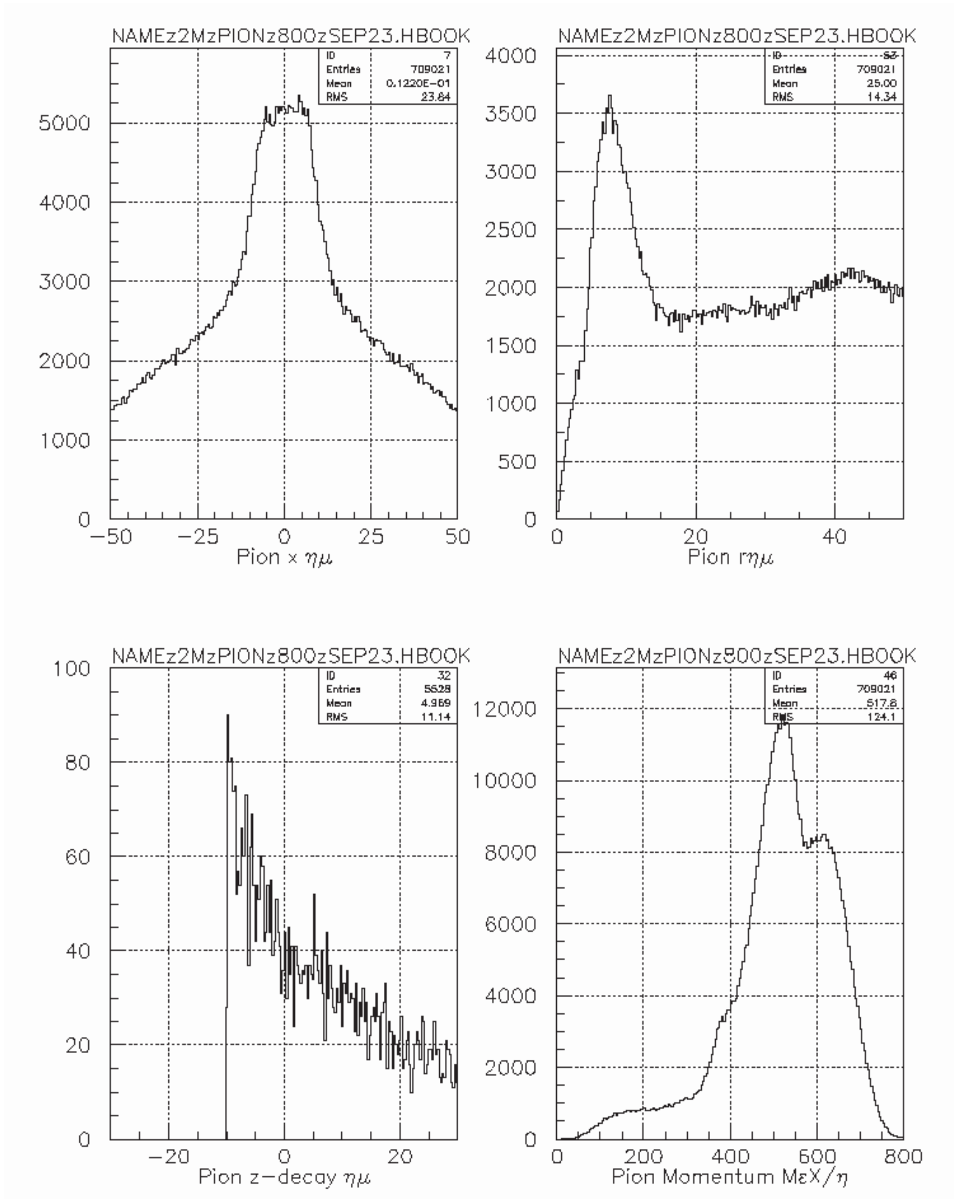

Figure 3: π^+ beam distributions at the 800 MeV/c incident π^+ beam. (a: upper-left) x/cm distribution at $z = 50$ cm; (b: upper-right) r/cm distribution also at $z = 50$ cm; (c: lower-lest) decay point z/cm distribution; (d: lower-right) momentum/MeV/c distribution at $z = 50$ cm. Incident π^+s of 2×10^6 were generated.

Figure 4: Schematic structure of the cylindrical triple-GEM detector C0

about its operation in a high-intensity beam environment with a beam halo of scattered particles and beam pions.

Table 2: Main parameters of the C0 GEM chamber.

Parameter	Value
Outer radius (readout layer)	7.0 cm
Inner radius (drift layer)	5.5 cm
Active length	30 cm
Thickness as standard TGEM	0.39 $\%X_0$
Thickness as light TGEM	0.15 $\%X_0$
2D readout azimuthal + longitudinal, pitch	400 μm
Number of channels	$\sim$ 2000
Position resolution	50-100 μm

During the first half of May 2007, an array of three MIT-prototype GEM detectors [6] built with GEM foils by Tech-Etch has been tested along with the new readout system under real experiment conditions. The test beamline provided 120 GeV protons from the Main Injector impacting on one of two 30 cm pieces of aluminum to produce a general purpose unseparated secondary beam. The protons spill out from the Main Injector during a 3.9 second flattop. The beamline can be also tuned to 120 GeV to select for non-interacting Main Injector beam protons. The intensity for this tune can approach 700 kHz of administrative maximum. The composition of the beam is mostly protons for the higher momentum tunes, mostly pions between 8 and 40 GeV and mostly electrons below 8 GeV. The lowest momentum tune achieved is 1 GeV and is about 60% electrons. The spot size is typically a few cm wide. The detectors were installed as a tracking telescope with 125 mm spacing between them. In the test experiment, the performance of the prototype chambers were confirmed measuring the cluster size distribution, the horizontal-vertical cluster amplitude correlation, the efficiency, and spatial resolutions. Details of the results of the test experiment can be found elsewhere [6].

2.2.2 Results of high intensity run

At the end of the test run, the beam intensity was maximized to study the behavior of the GEM detector array under highest achievable load by using the focused primary beam. Fig.5 shows the observed beam profiles with the 32 GeV defocused beam (left panel), 32 GeV focused beam (middle panel), and with the 120 GeV primary focused beam (right panel), yielding $\simeq 1.6 \cdot 10^5$ protons within 4s spills corresponding to 40 kHz peak rate. The size of the beam spot in the right panel is $\simeq$3 mm. Hence, within a circle of radius 3 mm, the beam consisted of about 25 kHz protons, corresponding to a peak intensity of about 1 kHz/mm^2. The time substructure of the spill was in bunches such that the peak intensities were probably considerably higher, which is however not exactly known. There was also a 60 Hz modulation such that the 4s spills could be shorter at times, however it is unknown by how much. While 1 kHz/mm^2 is a conservative estimate for the peak intensity, a much higher rate environment comparable to those reported from the COMPASS GEM chambers of $\simeq$100 kHz/mm^2 [7] or 25 kHz/mm^2 [8] might have been the actual case. The MIT GEM test detector array could accommodate the given intensities without any signs of degradation. It should be noted that the high-rate capabilities of GEM detectors have extensively been investigated at CERN. From these studies, rates even in the region of 1 MHz/mm^2 seem feasible [9].

2.2.3 C0 GEM detector rate capability

With a surface area of the proposed C0 element of 300 mm $\times$ $2\pi \cdot 70$ mm $\simeq 1.3 \cdot 10^5$ mm^2 for a C0 radius of 5 (10) cm, the chamber based on triple-GEM technology would be capable of detecting an integrated maximum rate $> (100-200)$ MHz of charged tracks originating from within the target in a conservative estimate. In comparison, the anticipated kaon intensity at J-PARC will be $\simeq$ 2 MHz with a kaon/pion ratio of $\simeq$ 1. Another serious concern is the effect of the beam halo on the performance of the C0 element. In E246, the previous C1 chamber had suffered from rate saturation and could not be used in the final analysis. According to an estimate from a Monte Carlo study by P. Gumplinger and M. Hasinoff [4], the halo intensity (parallel to the longitudinal direction) is expected to not exceed $\simeq$ 50 Hz/mm^2. The GEM design has two major advantages over proportional chambers. Firstly, the drift distance of the amplified charge to the readout plane is only 2-3 mm, which keeps the charge volume due to diffusion at a minimum. Secondly, the signal is provided by electron charges only, while the ion signal is strongly suppressed as they are efficiently absorbed by the upper GEM layers. Both these features of the GEM detector lead to very fast signals and small dead volumes.

The following consideration is for tracks that pass longitudinally through the cylinder shell and ionize the medium along the entire active length of 300 mm. The time constant τ for the GEM signal falloff is about 150 ns, however we assume $\tau = 300$ ns to be conservative. The size of the charge cloud is on the order of 350 μm, corresponding to an effective cross section of $\sigma_{eff} = 0.12$ mm^2 of dead area. For tracks that penetrate the GEM element perpendicularly, the intrinsic rate limit due to space charge limitation would hence be $R_{max}^{perp} = 1/(\sigma\tau) \simeq 50$ MHz/mm^2. On the other hand, if the track is passing parallel to the cylinder axis, the area of the charge cloud projected onto the readout plane is 0.35 mm $\times$

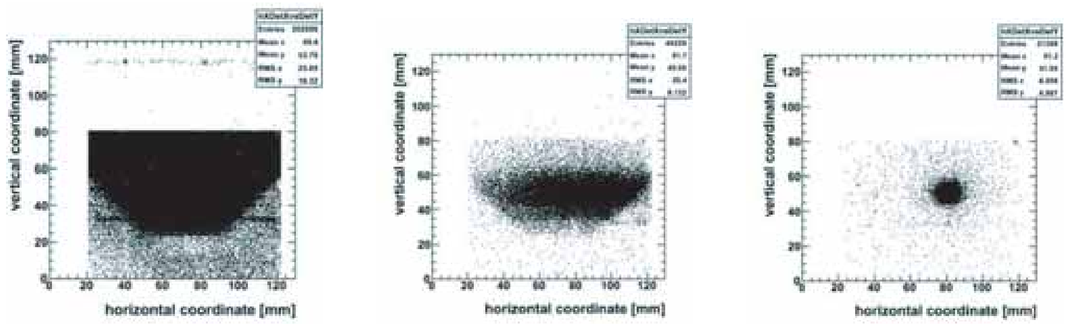

Figure 5: Beam profiles used in the rate capability test; with 32-GeV defocused beam (left), 32-GeV focused beam)middle, and 120-GeV primary focused proton beam (right).

300 mm $\simeq$ 100 mm^2. Assuming that the time constant is the same, the maximum tolerable rate intensity for parallel impact would be $R^{par}_{max} \simeq 60$ kHz/mm^2. From this consideration we conclude that the beam halo at J-PARC of < 50 Hz/mm^2 at a radius of about 10 cm from the beam axis will not be a concern for a near-target operation of a cylindrical GEM detector.

2.3 APD readout of CsI(Tl)

2.3.1 Prototype test with beam

As we described in the proposal and also in the FIFC report [1] we will replace PIN photo-diode of the E246 CsI(Tl) readout system by avalanche photo-diode (APD) in order to be able to accept much higher counting rate in TREK. An APD with the internal gain of 50-100 together with a matched current amplifier in conjunction with the full usage of FADC provides an ultimate rate performance which was essentially determined by the light decay time constant of CsI(Tl) of 0.9 μs, while it was limited in the case of a PIN diode by the dynamic range of the charge sensitive pre-amplifier and long shaping time constant of the main amplifier and its long output pulse to a few 10 kHz of module count rate.

To the FIFC we reported [1] a result of one module test using a Hamamatsu S8664-55 performed at INR (Russia). For cosmic rays a reasonably good energy resolution as well as a very good timing resolution of $\sigma_\tau = 3$ ns had been confirmed. In order to investigate one module performance with APD in the higher energy range corresponding to our actual experimental range of $E_\gamma < 250$ MeV, we have recently (in December) performed a beam test at the Laboratory Nuclear Science (LNS) electron accelerator ($E_{e^-} = 1.2$ GeV) of Tohoku University with an e^+ variable energy beam using a test trapezoidal CsI(Tl) module with the size of 3×3 cm in the front and 6×6 cm in the rear and a length of 25 cm ($13.5X_0$).

2.3.2 Test experiment procedure

The momenta of the positron beam were 100, 150, 200, 250, 300, 350, 400 MeV/c, and the length of beam spill was 4 s. The typical beam intensity was 1 kHz hitting the crystal, and the trigger rate is about a few ten Hz for normal runs; a positron beam was triggered with a

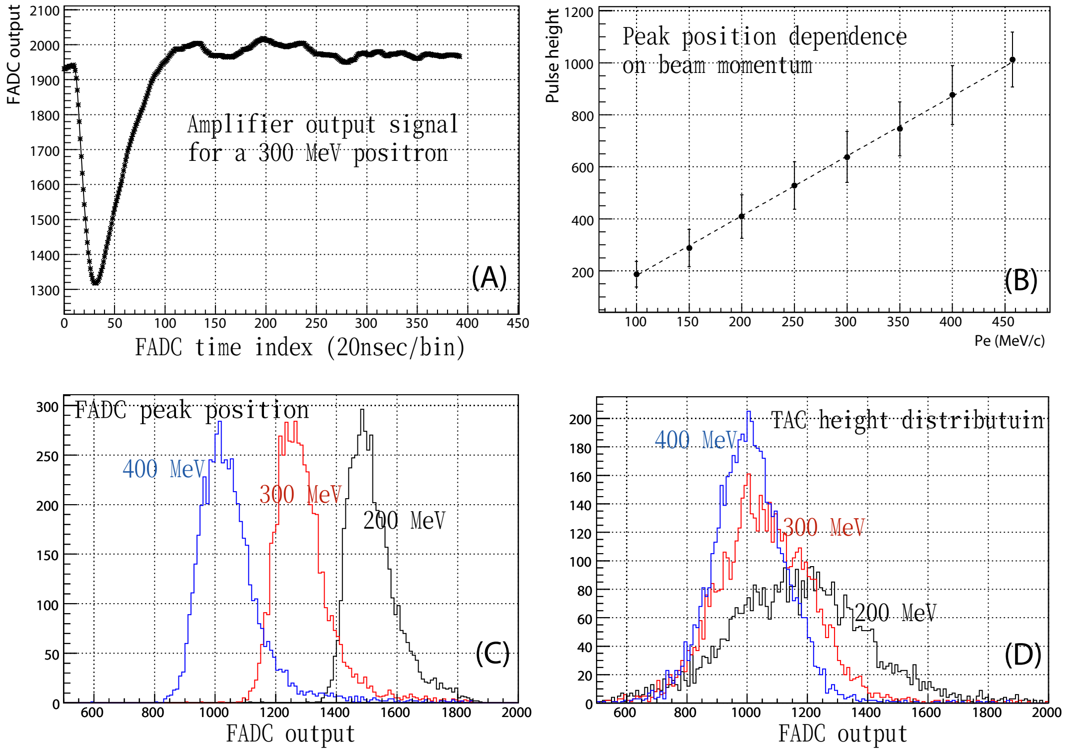

Figure 6: (a: upper-left) Typical output signal from the APD amplifier; (c: lower-left) Pulse height distributions for positron beam energy of 200, 300, and 400 MeV; (b: upper-right) Energy deposit peak position dependence on the beam energy; (d: lower-right) TAC pulse height (timing) distributions with 1 ns corresponding to about 40 channels.

plastic scintillator(PL), and a beam profiling counter. The size of a PL, whose output signal was used as the time origin, was $30 \times 40 \times 10$ mm. The raw signal from the photomultiplier of the PL was fed to the leading edge discriminator. The output of the discriminator was used as the trigger timing and start signal of the Time to Amplitude Converter (TAC). A beam profiling counter was installed in front of the CsI(Tl) crystal to determine the incident position of a positron. It consisted of two x and y layers of the scintillating fiber hodoscope. Each layers, which comprise sixteen fibers with their cross sections of 3×3 mm^2, determined the vertical and horizontal position of the incident positron on the front surface of the CsI(Tl) crystal. Four central fibers of both layers were used as the DAQ trigger.

The signal from the APD chip was fed to the amplifier which was developed by the INR (Moscow) group. The amplifier signals were recorded by a 50 MHz FADC[2], an FINESSE on the COPPER system [12]. The amplifier signal was also delivered to a Timing Filter Amplifier (TFA) and further to a Constant Fraction Discriminator (CFD) to provide a TAC stop signal for timing measurement.

[2]In oder to compare the ability of timing determination from FADC spectrum, other types of FADC with 250 MHz and 500 MHz were also tested as references.

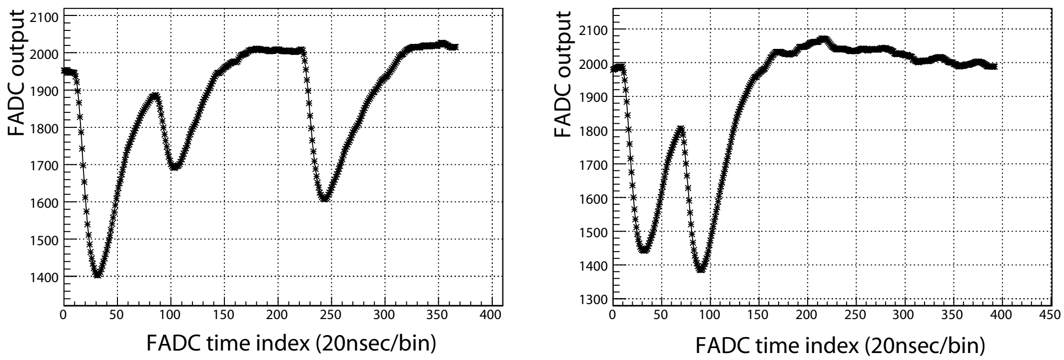

Figure 7: Signals of typical pule-up events in the high intensity run. One horizontal unit (50 FADC channels) is 1μ sec. Incomplete baseline recovery is due to the overshoot of the amplifier output which will be fixed.

2.3.3 Basic performance

In the Fig.6(a), a typical pulse shape for E_{e^+} =300 MeV. Rise time of the raw signal is about 400 nsec (from the start to the pulse to the peak) and the full width is about 1.8 μsec. It is about ten times shorter than the width of the PIN diode readout. There is a small overshoot signal after 1.8 μsec, which should be yet improved in the amplifier parameters. But it scarcely affects the energy resolution in the case of normal counting rate.

In the present quick analysis the peak point was regarded as energy deposit, because the pulse shape is very smooth. In Fig.6(b), the energy deposit distributions are shown for 400, 300 and 200 MeV positron beams hitting the center of the crystal. Zero energy corresponded to 1929 ch in the present case. So the difference from this ground level can be regarded as the energy deposit. In spite of large lateral shower leakage we could confirm a sufficient energy resolution enough to form a cluster to identify a decayed π^0.

Fig.6(c) shows the peak energy deposit position as a function of the beam momentum. The error bars does not indicate the error of this peak energy deposit but it shows the width (σ) of the energy deposit distribution fitted of a single Gaussian form. We could confirm that the peak energy deposit have the good linearity in the whole range. No signature of saturation in the APD and amplifier system was found.

Fig.6(d) is a TAC (timing) spectra between PL and APD for the whole events. Time resolution at this stage seems to be worth than that obtained as in the cosmic ray measurement, and to become relatively worse for lower beam energy. Details will be analyzed in regard to the energy dependence and crystal position dependence.

2.3.4 Pile-up characteristics and high rate performance

A high-instantaneous-intensity run was performed by maximizing the accelerator intensity, minimizing the duty factor for radiation to 0.4 s, and putting the thickest $\gamma \to e^+$ converter. An average instantaneous e^+ intensity of 35 kHz was achieved in the crystal. Under this condition we could observe several % of pile-up events as seen in Fig.7 and accumulated about 10^4 such signals yet to be analyzed in detail. Since the signal width and its rise-time are sufficiently short, it must be quite easy to deduce the pulse height (namely energy deposit in the module) reliably for post-pileup events (the events in which the first peak has the proper timing) by fitting the FADC signal shape. In the analysis, it will be investigated whether the fitted pulse height spectrum is the same as in low intensity run. For a pre-pileup event in which the second peak has the proper timing, it is also possible to fit and analyze the energy if we take the FADC data including a few μ sec past range by using an appropriate pulse shape response function. Certainly the output of the prototype amplifier used this time was not ideal with an overshoot and ringing and should be improved from now on. But also in the presence of such after-pulse effects the analysis of the energy will be feasible, compromising with energy resolution. In any case we conclude at the moment that separation of two pileup peaks with 1.0 μ sec separation should be possible allowing the average module rate of a few 100 kHz, as we intended in the proposal.

3 Further study of the K1.1-BR beamline

3.1 Reply to the FIFC reviewer

In the external reviewer report to FIFC [13] Dr.P.Pile of BNL admitted the soundness of the K1.1-BR beam optics design and the validity of the K^+/π^+ ratio estimate. At the same time he suggested several potential abilities of the beamline for the improvement of π^+ rejection power. His points were as follows:

- Investigate the possible addition of a variable vertical collimator upstream of the separator to reduce phi acceptance. Note this collimator need only have one jaw either top or bottom depending on the polarity of the separator.
- Doornbos (beam optics designer) pointed out that slit scattering at IFY is an issue and could well make pion contamination worse if not for the inclusion of a achromatic horizontal focus/slit downstream of the last bend. Double-check this assertion.
- Consider adding a variable (or fixed) horizontal collimator to allow momentum selection just downstream of the first sextupole.
- Note that a single 2-jaw collimator with the proper azimuthal orientation might be worth considering at the horizontal achromatic focus HFOC.
- RAYTRACE (or equivalent) simulation that takes into account 3rd and higher order optics should be done. quadrupole fringe fields should consider using rotated 2- jaw collimator here.

These points have been investigated and found that they do not have significant effects in rejecting the π^+ contamination at the end of the channel. A brief note by J.Doornbos who is responsible for the beam optics design in TREK is attached in Appendix A.1.

3.2 Optimization of the acceptance

The beam intensity is one of the key issues to determine the statistical accuracy of the experiment. Once given the accelerator beam condition and the thickness of the common T1 target, the acceptance of the beamline is the most important factor, which is in general

Table 3: Comparison of beamline acceptance and expected K^+ beam intensity

	Reference	n	Ω(mst %$\Delta p/p$)	I_{K^+} (/s)
B1 near to T1	[14]	0	6.0$\sim$ 6.5	3.0×10^6
B1 far from T1	[15]	0	4.5	2.1×10^6
Combined function B1	[16]	-6.75	7.8	3.6×10^6

fixed by the element configuration of the beamline front-end part. The T1 target concept of the Hadron hall, which enables the operation of at least two charged particle beams (K1.8 and K1.1) simultaneously suffers from a constraint in this regard. In the beginning of the beamline layout design, however, we still had sound policy of equal priorities for K1.8 and K1.1 realizing the total optimization of the experimental facility. Unfortunately enough, however, the precedence of the K1.8 installation with Day-1 experiments spoiled the overall optimization around the T1 target. K1.1 has now to be satisfied with smaller acceptance because the first element (bending magnet) has to be displaced to avoid a conflict with the K1.8 B1. This displacement resulted in reduction of the K1.1-BR intensity by 1/3 [15]. The beam intensity we are now based on in designing the experiment is this reduced intensity of the new beam optics , which we presented to FIFC [1]. We wanted to respect more or less the beam optics design efforts of the whole K1.1 beamline which uses the K1.1-BR as the upstream part of the channel.

We have been continuing the improvement of beam optics, especially in the view point of acceptance increase. Recently we found that the adoption of a combined function magnet in place of B1 can increase the acceptance drastically, by as large as 75% preserving the good K^+/π^+ ratio. Combined function is realized by adding a gradient to the dipolar field, namely putting an n-value as $B(x) = B_0(1 - nx/\rho)$. The best case was obtained for $n = -6.75$ by keeping the configuration of the other elements unchanged. The introduction of non-uniform-gap magnet may require for some technical problems to be solved. But we would like that a technical investigation will be made toward this definitive method to recover the acceptance of the beamline. One thing to be worked out as soon as possible is the check of the K1.1 beam optics and beam quality when the combined function magnet it used although the acceptance should be also high there.

4 Funding efforts and international cooperation

4.1 Status of budget requests

The cost of detector construction is estimated to be 280 Million Yen [1] not including the plant transfer cost of the He cryogenic system for the superconducting toroidal magnet. Considering still unclear situation of the J-PARC operation including the support of experimental programs, we have started this year budget request in Japan and Canada. In Japan we are applying to Grant-in-Aid research support money for the construction of most detector elements except for the target and for the operation of the collaboration. Request amount is 220 Million Yen for 5 year starting from next Japanese fiscal year 2008. The size of the money was almost uniquely determined by the limit for this category of the Grant-

Table 4: Funding efforts

Country	Source	Request	Year	Result known
Japan	Grant-in-Aid (S)	220 MYen	2008-2012	March 2008
Canada	NSERC	486 k$	2008-2010	Feb. 2008
U.S.A. (Hampton U.)	NSF	390 k$	2008-2010	–

in-Aid support money scheme. In Canada, the Canadian members submitted a request to NSERC (National Science and Engineering Research Council) for about 486 k$ including manpower and travel money *etc.* for 3 years also starting from 2008. This should cover the production cost of the target at TRIUMF. The group at Hampton University (U.S.A.) started also budget request for the TREK activity. Some parts of data-taking electronics are not considered yet and remain open questions. Foreign universities in the collaboration intend to take their own responsibilities in some detector elements contributing also to hardware cost. However, they have to wait for a more advanced status of the experiment of Stage 2 to start with budget requests.

4.2 Efforts for MoU *etc.*

Following the advice of the last PAC meeting, we have also started an effort to put the TREK international collaboration on much firmer basis. PAC recommended an exchange of "conditional MoU" (Memorandum of Understanding) between foreign institutions and IPNS/J-PARC. We realized, however, such an official process is too early for some foreign institutions before the TREK project is funded in that country. IPNS turned out to be also reluctant to exchange MoUs before TREK proceeds to stage 2, even if the MoUs are "conditional" . However, the INR institute in Russia is very willing to have an MoU to authorize its engagement in TREK and to facilitate its R&D activities already at the status of stage-1 approval. Quite recently we managed to exchange an MoU between the INR director and J-PARC Center director (Appendix A.2). We are thankful to the J-PARC center director Professor Nagamiya for his kind support.

Other universities are also very supportive to TREK experiment and encourages the faculty members to participate in this J-PARC experiment. Instead of MoU these universities kindly sent "support letters" to the J-PARC Center director and the IPNS director. They are from University of Saskatchewan, University of British Columbia, MIT, Hampton University, Iowa State University and University of South Carolina. The copies of these letters are attached in Appendix A.3.

5 Summary

In this report, we presented our recent progress since the last PAC meeting. High rate performance of detector elements and radiation hardness of some elements were clarified by means of test experiments and also Monte Carlo simulations. Hopefully, the concern of PAC is now resolved. Unfortunately, we could not make a progress in other fields of R&D and actual detector construction, since the experiment has not yet been funded and has no

Table 5: Efforts toward MoU exchange

Foreign institutions	Document form
INR (Russia)	MoU on detector development
University of Saskatchewan	Letter from management
University of British Columbia	Letter from Head, Department of Physics and Astronomy
MIT, Bate Accelerator Center	Letter from Director, Linear Accelerator Center, and Head, Laboratory for Nuclear Science
Hampton University	Letter from Dean, School of Sciences
Iowa State University	Letter from Dean, College of Liberal Arts and Sciences
University of South Carolina	Letter from Associate Dean for Research and Education

money. We concentrated our efforts, in this period, on budget requests and to make the international collaboration firmer. In order to proceed further, however, more advanced status of the experiment, namely a stage-2 approval is definitely necessary. We would like that this case will be considered seriously in the 4th PAC meeting in January, 2008.

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[14] J.Doornbos, “An 800 MeV/c separated kaon beam at J-PARC”, April, 2005; http://www-ps.kek.jp/imazato/trek/Doornbos1.pdf

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A Appendix

A.1 Answer to suggestions in K0.8 kaon review report

Answer to suggestions in K08 kaon review report

Jaap Doornbos, TRIUMF

September 20, 2007

The recent review of the proposed 0.8 GeV/c kaon beam by Dr. Phil Pile made several suggestions.

1 Scattering on IFY slit

The suggestion was to double check the importance of scattering on the IFY slit. I routinely calculated the scattering for many designs and always found that it was a serious problem. Now, I have checked it again in the most direct way. The Tungsten slit was 30 cm long, with a central 10 cm long flat piece with a full vertical width of 6 mm, and tapered before and after at an angle of 25 mr. The full width of the MS1 slit was 5 mm. The HFOC slit was open. The gradient in the separator was 50 kV/cm.

The calculation generated 2.5 million rays in a large phase space. With the scattering turned off 7 pions reached the end. When the scattering was turned on 666 pions reached the end, and 323,099 kaons. Assuming that the ratio between pions and kaons in the unseparated beam is 600, the 666 pions represent a pion to kaon ratio in the separated beam of 1.24. When the mass slit is opened to 7 mm, there are 46 pions without scattering but 996 pions with scattering included. These calculations were done with the second order program REVMOC which does not take into account third order and higher order aberrations.

These calculations confirm that scattering on IFY is a serious problem. As shown in the reports, it can be handled with the HFOC slit.

2 Higher order raytrace programs

All calculations for the direct pion contamination are done with the higher order program ZGOUBI, which is completely equivalent to Enge Kowalski

1

RAYTRACE, and agreed with RAYTRACE very well for LESB3 and for the 1.8 GeV/c kaon beam at Brookhaven.

3 Momentum collimator just before separator

The calculations were done with ZGOUBI for the direct pion contamination but a momentum slit just before the separator gave no improvement.

4 Theta Phi collimator just before separator

Calculations were done for the direct pion contamination with ZGOUBI. Figure 1 shows the X-Y distribution just before the separator and at the position of HFOC. Both cases show a similar effect of vertical slits on the pion contamination. By slightly closing the bottom vertical slit at HFOC the direct pion contamination can be reduced from a pi to k ratio of 0.46 to 0.19. Since there is not much space before the separator it is better to use the vertical slit at HFOC.

5 Rotated 2-jaw collimator at HFOC

It was found that slanting the HFOC slit gave not much improvement.

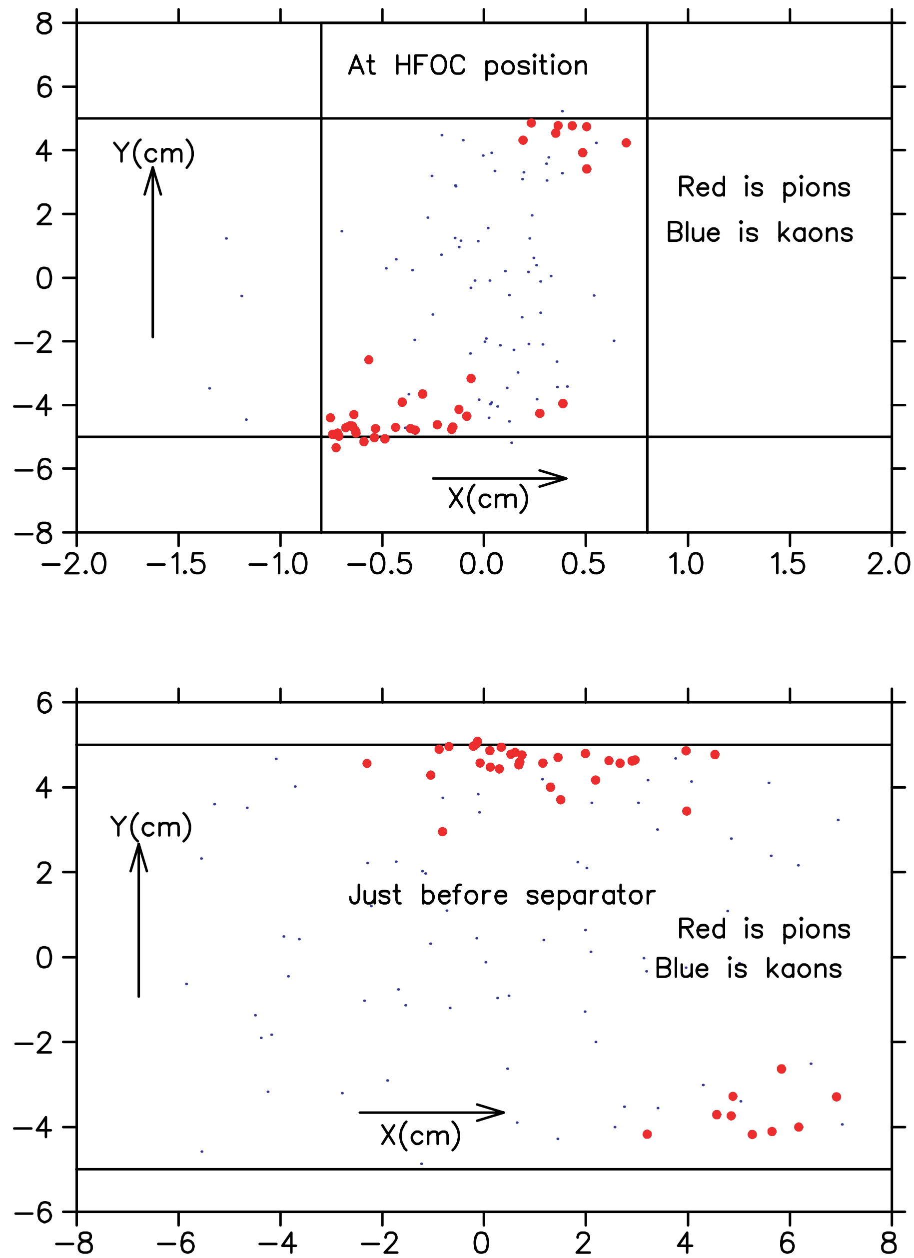

Figure 1: X-Y distributions for pions and kaons just before the separator at the bottom and at the HFOC position at the top. The vertical lines in the top plot indicate the horizontal width of the HFOC slit.

3

A.2 MoU between INR(Russia) and J-PARC Center

Memorandum of Understanding
On
Cooperation between Japan and Russia for the J-PARC Experiment E06 (TREK) "Measurement of T-violating Transverse Muon Polarization in $K^+ \to \pi^0 \mu^+ \nu$ Decays"

1. There are two parties to this Memorandum of Understanding:

- J-PARC Center
- Institute for Nuclear Research (INR), Russian Academy of Sciences

2. The purpose of this Memorandum of Understanding is to facilitate the J-PARC experiment E06 (TREK) "Measurement of T-violating Transverse Muon Polarization in $K^+ \to \pi^0 \mu^+ \nu$ Decays" which is being carried out by an international collaboration including the INR group.

3. Both parties acknowledge that this experiment, which is searching for new physics beyond the standard model, was granted stage-1 approval by the PAC in July 2006 due to its high scientific merit, and they agree to provide support to the E06 (TREK) collaboration subject to budgetary constraints.

4. J-PARC will make an effort for the construction of the K1.1 beam line including its branch beam line which will be used by the E06 (TREK) experiment, so that they can install the K1.1-BR beam line in a timely manner. J-PARC does not charge any fee for the use of its particle beams.

5. INR will provide personnel and facility resources to the E06 (TREK) collaboration to help design and construct the readout system for the CsI(Tl) calorimeter and other sub-detector systems at INR in collaboration with members of INR –subject to budgetary constraints.

6. This Memorandum of Understanding takes effect on the day of its signature. Its duration is for three years, renewable by mutual consent. It may be modified or amended at any time by mutual consent.

S.Nagamiya Director , J-PARC Center	V.A. Matveev Director, INR
Date : Dec. 20, 2007 Place: Tsukuba	Date : 19. 12. 2007 Place: Moscow

A.3 Support letters from foreign institutions

UNIVERSITY OF SASKATCHEWAN

Dr. Bryan Schreiner
Assistant to the Vice-President Research
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May 23, 2007

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High Energy Res. Accel. Org., KEK
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Dr. F. Takasaki
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RE: J-PARC 50-GeV PS Experiment E06

Dr. Nagamiya and Dr. Takasaki:

I am writing in regard to the J-PARC 50-GeV PS Experiment E06: Measurement of T-violating Transverse Muon Polarization in $K^+ \rightarrow \pi^0 \mu^+ \nu$ Decays. The University of Saskatchewan is honored to be collaborating in this important experiment.

In support of Dr. Chary Rangacharyulu and his Canadian team, the University of Saskatchewan's International Research Office offers its commitment to identify appropriate Canadian and international funding agencies to support this collaboration, and to assist in the grant application process.

If you require further information, please contact Anne Neufeld, Manager, International Research at anne.neufeld@usask.ca.

Regards,

Dr. Bryan Schreiner
Assistant to the Vice-President Research

cc: Prof. K. Tokushuku
Prof. J. Imazato

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Robert P. Redwine
Director MIT-Bates Linear Accelerator Center
Professor of Physics

Richard G. Milner
Director MIT Laboratory for Nuclear Science
Professor of Physics

October 25th, 2007

Dr. Shoji Nagamiya
J-PARC Center, Director
High Energy Accelerator Research Organization (KEK)
1-1, Oho, Tsukuba-shi, Ibaraki-ken
305-0801 Japan

Dear Dr. Nagamiya:

We are writing this letter to express our strong support for the Time Reversal violation Experiment with Kaons (TREK) project.

We recognize the high scientific merit of this project in that it may reveal a new source of CP violation beyond the Standard Model, which would be an important step towards an explanation of our existence due to the matter-antimatter asymmetry. With the high sensitivity of TREK to new physics, even an upper limit would strongly constrain the New Standard Model (NSM) of physics to emerge in the era of LHC. It is important to note that several independent but complementary high-precision experiments are required to constrain sufficiently the parameter space of extensions to the Standard Model. For example, we are also involved in the preparation of the US search for a neutron electric dipole moment (nEDM).

Our interest in TREK has been initiated by our MIT colleague Dr. Michael Kohl, who will take the position of Assistant Professor at Hampton University and Jefferson Laboratory in January 2008. He is committed to take on a leadership role for the required tracking upgrade of the TREK apparatus, which in particular involves development and construction of a novel cylindrical GEM (Gas Electron Multiplier) detector.

We at MIT and Bates have considerable expertise in this new technology of GEM detectors. One of our faculty members (Prof. B. Surrow) is leading the effort to design and build a forward GEM tracker (FGT) for the tracking upgrade of the STAR experiment at RHIC based on GEM technology. A cooperative initiative with Tech-Etch Inc., a local company in Plymouth, MA, has been undertaken to industrialize the GEM foil production process.

Moreover, new fast counting readout electronics based on FPGA technology have been developed at MIT-Bates. Recently, a new prototype GEM telescope including readout has been successfully tested at Fermilab under intense beam conditions at the Meson Test Beam Facility.

In a future collaborative network with Dr. Kohl, we expect to be able to deliver high-quality GEM foils for direct use in the detector construction project of TREK. Also, the new readout system is suitable to be applied to the GEM detectors for TREK with only moderate modifications.

We wish every success for the TREK collaboration and hope that this project can be realized in a timely manner. In particular, we believe it is important for TREK to be fully approved at the next PAC meeting in January 2008.

Sincerely,

Robert P. Redwine

Richard G. Milner

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2 November 2007

Dr. Shoji Nagamiya
Director
J-PARC Center
High Energy Accelerator Research Organization (KEK)
1-1, Oho, Tsukuba-shi, Ibaraki-ken
305-0801 Japan

Dear Dr. Nagamiya,

I'm writing to express Hampton University's strong support for the Time Reversal violation Experiment with Kaons (TREK).

We recognize the high scientific merit of this project as it may reveal a new source of CP violation beyond the Standard Model, one of the requirements formulated by A. Sakharov to explain the matter-antimatter asymmetry in the Universe.

As a historically black university we provide a quality education to students from groups underrepresented in sciences such as nuclear and particle physics, mainly African American and women students. We recognize that the TREK experimental project will provide an excellent opportunity for first-class student education.

Our interest in TREK has been initiated by Dr. Michael Kohl who we have hired as a new joint Assistant Professor at Hampton University and Jefferson Lab to start in January 2008. He has decided to take on the responsibility for the required tracking upgrade of the TREK apparatus, which in particular involves development and construction of a novel cylindrical GEM (Gas Electron Multiplier) detector.

Hampton University will do whatever we can to support the effort of Dr. Kohl and to make TREK a success. Recently, we have filed a grant application to the National Science Foundation (NSF) to support Dr. Kohl's activity as Principal Investigator, requesting about $130,000 per year until August 2010. We have also recently filed a pre-proposal to NSF for a five-year extension of our ongoing NSF Physics Frontiers Center (PFC) "Center for the study of the Origin and Structure of Matter", of which TREK has been proposed to become a subproject. Upon invitation by the NSF, a full proposal will be due by the end of January 2008, with a start of the funding support envisioned for September 2008.

I hope that this project can be realized in a timely manner. In particular, it would be welcome if TREK can be fully approved by the time of the next meeting of the J-PARC Program Advisory Committee (PAC) meeting in January 2008. In this regard, a full approval of TREK by the PAC would significantly enhance the chances for the aforementioned Physics Frontiers Center.

Sincerely yours,

Claudia Rankins
Dean, School of Science

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C.C. Prof. Katsuo Tokushuku (J-PARC PAC chairman) – IPNS, etc
Prof. Jun Imazato (TREK spokesperson) – jun.imazato@kek.jp
Prof. Mike Hasinoff

November 19, 2007

Dear Professor Nagamiya,

I am writing to express the strong support of the Department of Physics & Astronomy at the University of British Columbia for the Time Reversal Experiment with Kaons (TREK), E06, which will be performed at the new high-intensity proton accelerator, J-PARC in Tokai, Japan. UBC is very honoured to be collaborating in this high priority international effort to search for a new source of CP- or T-violation beyond that currently contained in the highly successful Standard Model of Particle Physics. I know that such a new source of CP-violation is one of the requirements postulated by Andrei Sakharov to explain the matter-antimatter asymmetry in the Universe, and hence this is a very important and necessary experiment.

In addition to our sub-atomic physics group (that includes 2 members in the BaBar collaboration) our department also has researchers working in theoretical and experimental astroparticle physics, and the TREK experiment at J-PARC will provide another strong link to our existing expertise in this emerging new field of physics. Our department has excellent machine-shop and electronics personnel who are available to assist our faculty members at highly subsidized rates. We are also able to provide our graduate students and faculty members with excellent computing resources and data analysis support.

I understand that the TREK collaboration has now demonstrated (in Monte Carlo) that they will be able to obtain an experimental sensitivity of ~1:10,000 which might uncover some new physics, or, at the very least, strongly constrain the many postulated extensions of the Standard Model. I wish the TREK collaboration every success in this very important 2nd generation T-violation experiment at J-PARC.

Sincerely,

Jeff Young
Professor and Head

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December 6, 2007

Professor Shoji Nagamiya
Director, J-PARC Center
High Energy Accelerator Research Organization
Oho 1-1, Tsukuba-shi, Ibaraki-ken
305-0801 Japan

Dear Professor Nagamiya:

I have had the opportunity to discuss with Professor E. Walter Anderson, who is a faculty member in our Department of Physics and Astronomy, regarding his participation in the E06 (TREK) experiment for the **Measurement of T-violating Transverse Muon Polarization in $K^+ \rightarrow \pi^0 \mu^+ \nu$ Decays** to be performed at J-PARC in Japan.

As Dean of the College of Liberal Arts and Sciences at Iowa State University, I am pleased to endorse his efforts in the TREK Collaboration. We regard an active research program, whenever possible, as an important part of each faculty member's duties. As for all our faculty members, Iowa State University has a program for sabbatical leave, provides support services for proposal and grant preparation, and has comprehensive laboratory facilities.

In the research fields of Particle and Nuclear Physics, Iowa State University has had a long tradition at the major national and international laboratories. Currently several faculty are performing experiments at SLAC, Fermilab, Brookhaven and CERN, for which they have designed and constructed components of the detectors utilizing the university's professional staff and resources. Professor Anderson has specialized in photo-optical detectors, most recently for experiments at Fermilab and CERN.

We sincerely hope that a final approval from the J-PARC Program Advisory Committee will soon be achieved, so that the submission of grant proposals can go forward to the Federal funding agencies in the United States.

Sincerely,

Michael B. Whiteford, Dean
College of Liberal Arts and Sciences
Iowa State University

Cc: Professor Katsuo Tokushku
Professor Jun Imazato
Professor Eli Rosenberg

UNIVERSITY OF SOUTH CAROLINA

December, 2007

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RE: J-PARC 50-GeV PS Experiment E06 (TREK Collaboration)

Dr. Nagamiya and Dr. Takasaki:

I am writing in regards to the J-PARC 50-GeV PS Experiment E06: "Measurement of T-violating Transverse Muon Polarization in $K^+ \rightarrow \pi^0 \mu^+ \nu$".

In support of the Intermediate Energy Nuclear Physics team, the University of South Carolina Office of Research offers its commitment to identify appropriate USA and international funding agencies to support this collaboration and to assist in the grant application process. Particularly, Dr. Djalali and his colleagues in the Intermediate Energy Nuclear Physics team will support the ongoing preparation of experiment E06 with computer simulations of the experimental setup and detector response. These simulations and later analysis of data will be performed on the cluster of computers which are available at the USC Department of Physics and Astronomy

If you require further information, please contact Dr. Chaden Djalali, Chair of the Department of Physics and Astronomy at USC.

My very best wishes to you on this research venture.

Dr. Timothy A. Mousseau
Associate Dean for research and Graduate Education
College of Arts and Sciences

Cc: Dr. K. Tokushuko
Dr. J. Imazato

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