Proposal for J-PARC 50 GeV Proton Synchrotron

Measurement of the strong interaction induced shift and width of the 1s state of kaonic deuterium at J-PARC

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Abstract

The antikaon-nucleon ($K^{bar}N$) interaction close to threshold provides crucial information on the interplay between spontaneous and explicit chiral symmetry breaking in low-energy QCD. In this context the importance of kaonic deuterium X-ray spectroscopy has been well recognized, but no experimental results have yet been obtained due to the difficulty of the measurement.

We propose to measure the shift and width of the kaonic deuterium 1s state with an accuracy of 60 eV and 140 eV, respectively. These proposed J-PARC results together with the kaonic hydrogen data (KpX at KEK, DEAR and SIDDHARTA at DAΦNE) will then permit the determination of values of both the isoisospin I=0 and I=1 antikaon-nucleon scattering length and will provide the most stringent constraints on the antikaon-nucleon interaction, promising a breakthrough for this field.

Making use of the existing E15 apparatus at J-PARC upgraded with a recently developed X-ray detector system, and based on the experience gained with a test measurement of kaonic deuterium with SIDDHARTA, we have developed an experimental setup proposed for the kaonic deuterium measurement at J-PARC. Refined Monte Carlo studies were performed, including the investigation of the background suppression factors with this setup. Assuming a beam power of 30 kW and 100 shifts of beam time, we demonstrate the feasibility to determine the shift and width of the kaonic deuterium atom 1s state with the aimed accuracy:
shift = 60 eV and width = 140 eV (for an assumed width of 750 eV).

Summary of the proposed experiment:

Beam line: K1.8BR
Primary beam: 30 GeV, 30 kW
Secondary beam: 0.7 GeV/c, K^-
Beam intensity: 3.0×10^4 per spill (6 s repetition rate)
Reaction: ground state X-ray transitions of stopped kaons in gaseous deuterium
Detectors: Silicon Drift Detectors (SDDs) in addition to the E15 setup
Target: Gaseous deuterium (5 % liquid deuterium density)
Beam time: 12 shifts (4 days) for commissioning with hydrogen
100 shifts (33 days) data run with deuterium
Estimated accuracy:
1s shift: $\varepsilon_{1s} \sim$ 60 eV
1s width: $\Gamma_{1s} \sim$ 140 eV

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1 Introduction

1.1 Physics motivation

The antikaon-nucleon (K^{bar}-N) interaction close to threshold provides crucial information on the interplay between spontaneous and explicit chiral symmetry breaking in low-energy QCD. Experimental investigations in this field have been performed over many years, such as scattering experiments and X-ray spectroscopy of kaonic atoms [1]. Theoretical investigations based on the experimental results have been performed [2-13], but these approaches are very complicated due to the presence of the Λ(1405) resonance located just below the K^-p threshold. At present, there are no lattice QCD calculations of antikaon-nucleon scattering lengths, although a theoretical framework has recently been proposed [14]. In particular, the kaonic atom X-ray data provide the most precise values of the antikaon-nucleon scattering at threshold energy.

The K^-p interaction is now well understood from the recent results of kaonic hydrogen obtained from KpX [15] at KEK, DEAR [16] and finally from SIDDHARTA at DAΦNE [17] and the theoretical calculations based on these results [18, 19]. A milestone was the KpX experiment which first used fiducial volume cuts to suppress background, thus solving the long standing kaonic hydrogen puzzle.

Although the importance of kaonic deuterium X-ray spectroscopy has been well recognized for more than 30 years [20], no experimental results were obtained so far due to the difficulty of the X-ray measurement.

"The necessity to perform measurements of the kaonic deuterium ground state observables is justified by the fact that, unlike the case of pionic atoms, the measurement of only the kaonic hydrogen spectrum does not allow – even in principle – to extract independently both s-wave K^{bar}*-nucleon scattering lengths* a_0 *and* a_1*."*, quoting from U.-G. Meisser [21].

The kaonic deuterium X-ray measurement represents the most important experimental information missing in the field of the low-energy antikaon-nucleon interactions today.

With this proposal, using as input the experience gained with the SIDDHARTA experiment (kaonic hydrogen X-rays determined with with presently the highest precision and an exploratory measurement on kaonic deuterium), we have now established the feasibility of measuring the kaonic deuterium X-ray spectrum at J-PARC. The expected results, together with those of SIDDHARTA will provide the most stringent constraints on the antikaon-nucleon interaction, promising a breakthrough in this field.

The kaonic hydrogen and deuterium data will also be indispensable when applying unitarized chiral perturbation theory to account for the Λ(1405) resonance to kaon-hadronic systems in nuclear matter. There are several hints of K^- quasi-bound states in few-body nuclear systems by FINUDA [22] at DAΦNE and DISTO [23] at SATURNE. In addition, with E15 [24], a search for a K^-pp bound system is ongoing at J-PARC, giving urgency to precise measurements of kaonic atom systems.

1.2 Present state-of-the-art

Recently, the most precise values of the strong-interaction shift and width of the kaonic hydrogen 1s state were obtained by the SIDDHARTA experiment [17]. The result of the pioneering KpX experiment (KEK-PS E228) together with DEAR and SIDDHARTA are shown in figure 1.

In the latest SIDDHARTA kaonic hydrogen measurement at DAFNE, an exploratory kaonic deuterium measurement was also made, in part to clarify the hydrogen background as well as to set a limit on the strength of the deuterium signal [25].

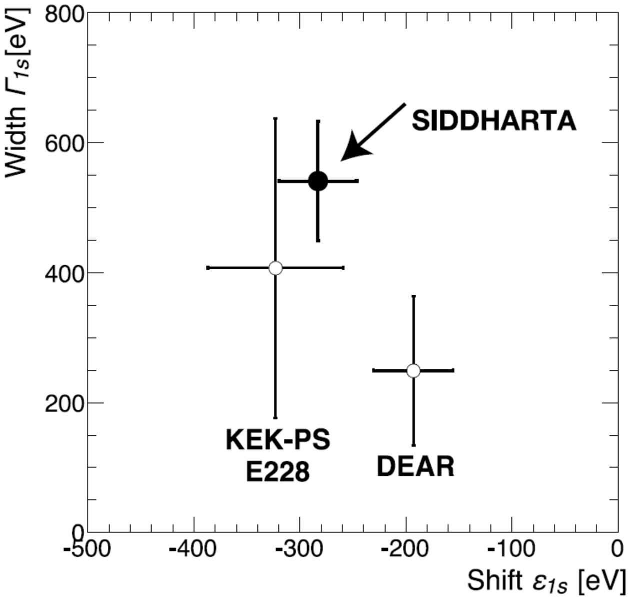

Figure 1: Comparison of experimental results for the strong-interaction shift and width of the kaonic hydrogen 1s state.

The analysis of the kaonic deuterium data showed some fluctuations in the area of interest and delivered an upper limit of the K-series transition yields (see figure 2), if the values for shift and width of the K-series transitions are taken from theory: shift = –800 eV and width = 750 eV. The upper limits for the yield of the K-series transitions were derived in this analysis: $Y(K_{tot}) < 0.014$ and $Y(K_{\alpha}) < 0.004$ (CL 90%), for a target density of 1.5% of liquid deuterium density (LDD).

The experimentally determined shift and width are related to the s-wave scattering lengths at threshold [1]. Because of isospin conservation, only the average value of the isospin I=0 and I=1 scattering lengths (a0 and a1) was obtained from the kaonic hydrogen measurement. In order to determine the isospin dependent scattering lengths, a measurement of **the shift and width of the kaonic deuterium 1*s* state is definitely needed [18-21, 26-28].**

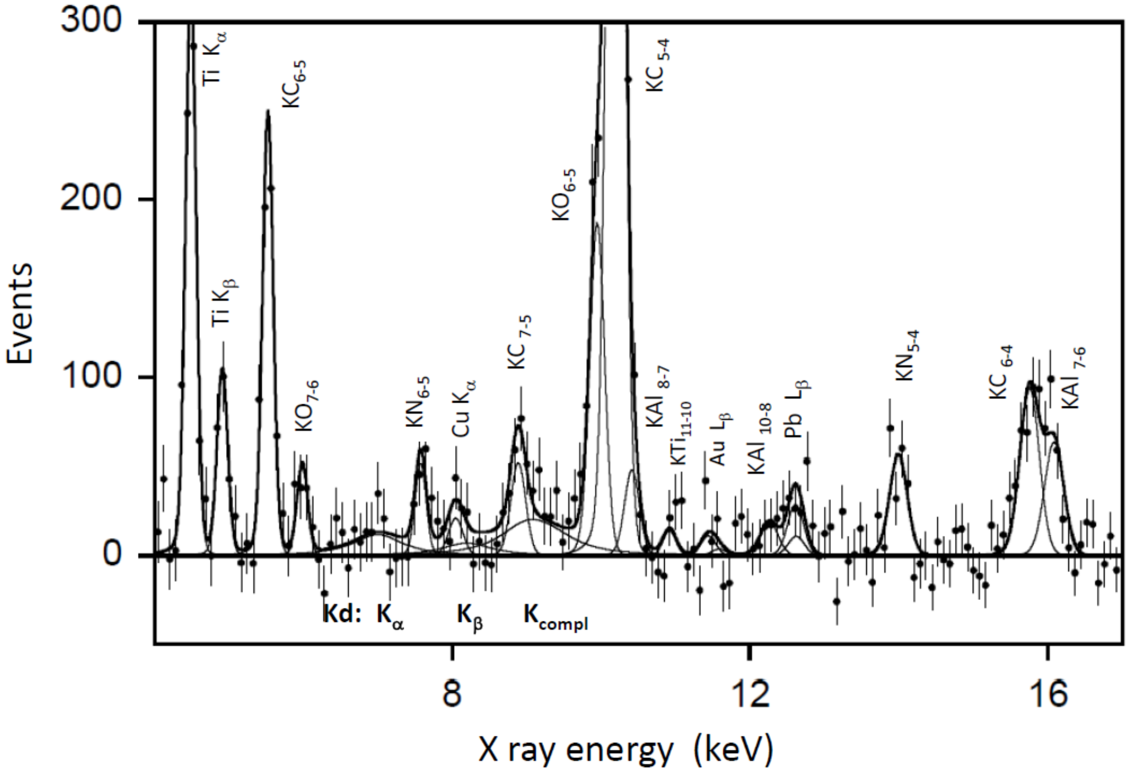

Figure 2: Example of a fit of kaonic deuterium X-ray lines using theoretical estimated values for shift – 800 eV and width 750 eV (taken from [25], figure 2).

On the theoretical side there are many recent publications, predicting quite consistent values of the shift and width for the kaonic deuterium 1s state (see table 1).

a_{K^-d} [fm]	ϵ_{1s} [eV]	Γ_{1s} [eV]	ref.
-1.58 + i 1.37	-887	757	Mizutani 2013 [4]
-1.48 + i 1.22	-787	1011	Shevchenko 2012 [5]
-1.46 + i 1.08	-779	650	Meißner 2011 [1]
-1.42 + i 1.09	-769	674	Gal 2007 [6]
-1.66 + i 1.28	-884	665	Meißner 2006 [7]

Table 1: Compilation of predicted K^-d scattering lengths $a_{K\text{-}d}$ and corresponding experimental quantities ε_{1s} and Γ_{1s} (taken from [25], table1).

2 Proposed experimental method

The proposed experiment will measure the transition X-ray energies to the ground state of kaonic deuterium atoms with recently developed SDDs using the experience gained with Silicon Drift Detectors (SDDs) at KEK with the E570 [29] experiment. In addition, charged particle tracking for background reduction will be used, previously developed for the KpX experiment E228 [15] at KEK, as well as the background studies performed for the E17 experiment [30] at J-PARC to measure $K^{-3}He$. Finally the results obtained from an exploratory measurement of kaonic deuterium with SIDDHARTA [25] were used to confine the values for X-ray yield, shift and width, used in the Monte Carlo studies in this proposal.

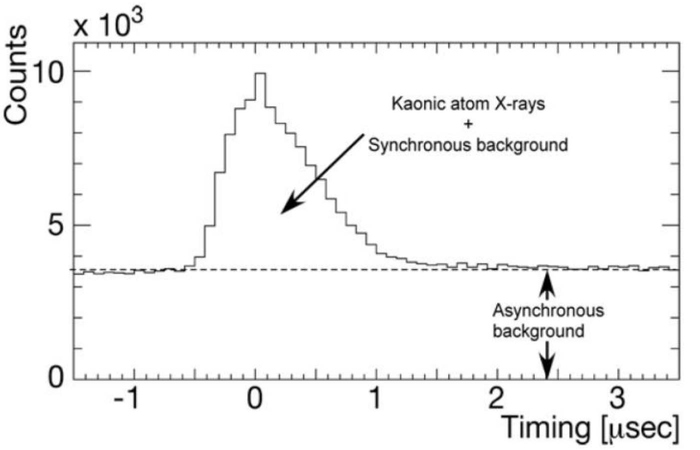

Figure 3: Drift time distribution of the SIDDHARTA SDDs at a temperature of 170 K; the measured drift time (FWHM) with the "old" SDD was approximately 700 ns.

The experimental challenge of the proposed experiment is the very small kaonic deuterium X-ray yield and the difficulty to perform X-ray spectroscopy in the high radiation environment of an extracted beam. It is therefore crucial to control and improve the signal-to-background ratio for a successful observation of the kaonic deuterium X-rays. There are two types of background sources; correlated (synchronous) and uncorrelated (asynchronous) to the incoming K^-.

The asynchronous background originates from the production target. This background can be suppressed by additional shielding and better timing of the SDD itself. The broadening of the peak in figure 3 corresponds to the drift time distribution of charges in the SDDs, which depends (along with the shape) on the working temperature of the SDDs. Running the SDDs at a temperature below 30 K (compared to 170 K as shown in figure 3) reduces the drift time below 40 ns for the new type of large area SDDs (0.64 cm^2).

The synchronous background originates from secondary particles generated by the decays and reactions of kaons (kaon absorption in the target gas or in the walls). These background events can be suppressed by charged particle tracking, determining the stopping point of the kaons within the target. Therefore the excellent tracking capability of the E15 apparatus is essential for the proposed measurement.

2.1 E570 – Kaonic helium measurement at KEK

For the E570 [29] experiment at KEK (see figure 4) eight silicon drift detectors (SDDs) produced by KETEK GmbH [31] were used as X-ray detectors, each with an effective area of 1 cm^2 and a 260 μm-thick active layer. The electrons produced by an X-ray hit in the SDDs drift radially toward the central anode where they are collected. The small anode size (and hence small capacitance) is essential to realize the good energy resolution of ~190 eV (FWHM) at 6.4 keV, about twice as good that of the Si(Li) detectors used in the previous experiments. The reduced active layer thickness, less than 1/10 of the previously used Si(Li) detectors, helps to reduce continuum background caused by Compton scattering inside the detector.

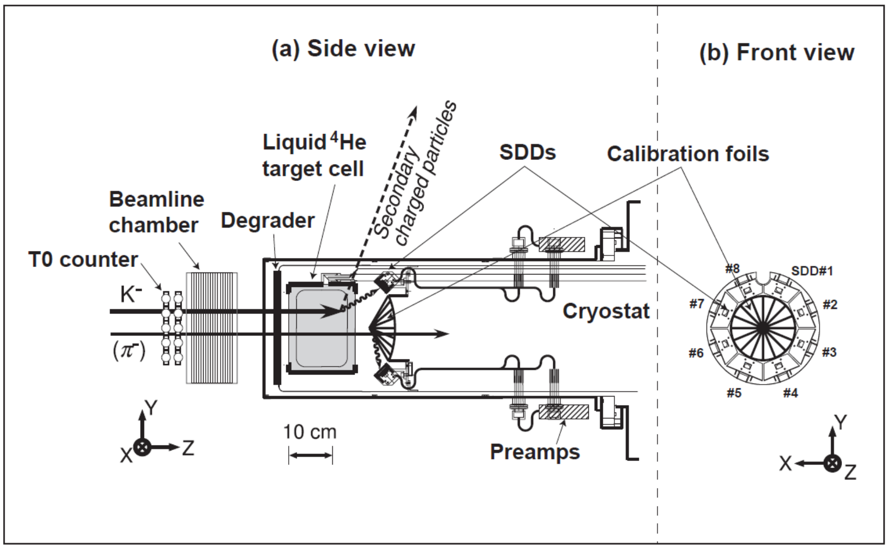

Figure 4: (a) A schematic side view of the E570 setup around the cylindrical target with the X-ray detection system. (b) A front view of the SDD assembly. Eight X-ray detectors were mounted on holders tilted at a 45 degree angle to the beam centre in an annular-shaped pattern. Fan-shaped high-purity titanium and nickel foils are put alternately on a cone-shaped support located on the beam axis (figure 2 from [29]).

Another important feature of the E570 experiment was the possibility to perform fiducial volume cuts. The kaon-reaction vertex was reconstructed from an incident kaon track and an outgoing secondary charged particle track. The secondary charged particles were emitted from kaon absorption on the nucleus. To reduce background it was required that the kaon-reaction vertices should be within the target. This requirement ensured that the X-rays which are detected in coincidence with the secondary charged particles were emitted from the target.

***The experiment E570** clearly shows the excellent capability of SDDs for X-ray spectroscopy of kaonic atoms in the environment of an accelerator. In addition the fiducial volume cut technique developed at the **KpX experiment** has proven to be very efficient in suppressing background events originating from the wall and has to be applied as well in the proposed kaonic deuterium X-ray measurement.*

2.2 E17 experiment at J-PARC

The E 17 experiment at J-PARC [30] proposes to measure the strong-interaction shift of 3d → 2p X-rays of kaonic helium-3 atoms with a precision better than 2 eV (setup figure 5).

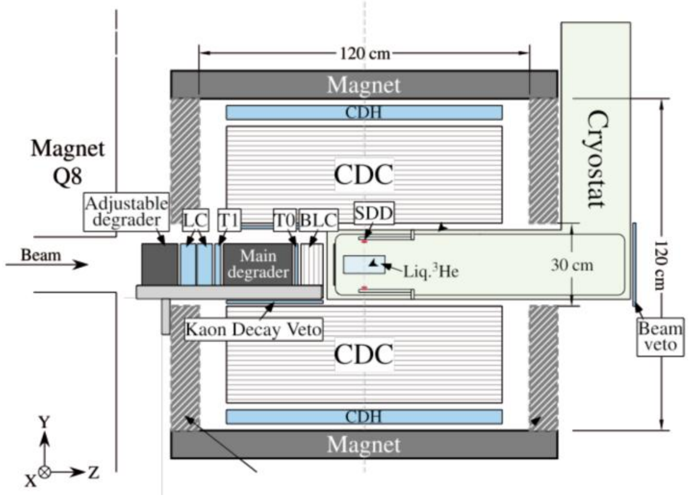

Figure 5: E17 setup, using part of the K1.8BR spectrometer.

In the simulations done for E17, it was assumed that the background originates from hits of charged particles and high energy γ-rays which partly come from accidental beam particles, and partly from coincident secondary particles emitted after K^- absorption in helium-3. An estimate based on the experience gained in the KEK E570 experiment was made. The results are summarized in table 2.

	KEK E570	J-PARC E17
Time Resolution ΔT (ns)	130	220
SDD Efficiency ϵ_{SDD} (%/all SDDs)	0.13	0.95
SDD Single Hit rate F_{SDD} (s^{-1})	105	50
SDD OR / spill	210	100
spill length (s)	2	2
Spill duty factor D_{spill}		0.3
Continuum BG / 50 eV /2000 KHeL_α	25	18 (estimation)
from kaon absorption	14	14 (estimation)
from beam	11	4 (estimation)

Table 2: Comparison of the experimental conditions at KEK (E570) and J-PARC (E17). Background counts for KEK E570 were evaluated by using timing and energy spectra. Time resolution and SDD OR / spill for J-PARC E17 are measured values in the beam commissioning in November 2010.

A better time resolution of the new SDDs of about 40 ns could be achieved. First due the shorter drift length (smaller area of the new SDDS of 0.64 cm^2 compared to 1 cm^2 of the old SDDs) and second due to the lower working temperature (< 40 K). In addition we study the possibility to take advantage of the correlation between drift time and rise time of the SDD signal for further improvement of the time resolution and therefore a further suppression of the beam related asynchronous background. Using the numbers given in table 2 we estimate that the background ratio from kaon absorption (synchronous background) to the asynchronous beam background for a gaseous target (5% of LDD), including the shorter drift time of the new SDDs, will be approximately 3:1, which we take into account.

We used the background evaluation done by the ***E17 collaboration*** *as input for the Monte Carlo studies. Essential for a further reduction of the uncorrelated beam background is the improvement of the SDD timing below 40 ns.*

2.3 Results of an exploratory measurement with SIDDHARTA

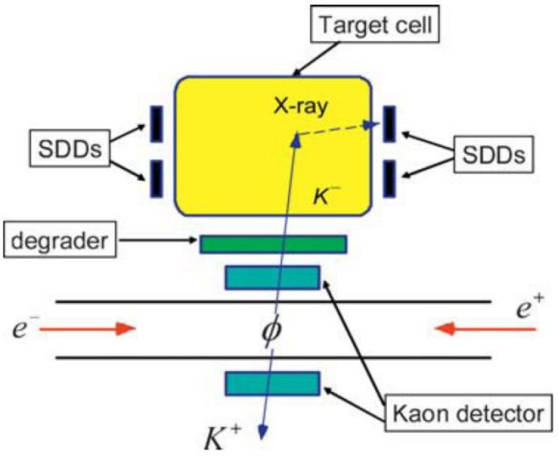

Figure 6: Drawing of the SIDDHARTA experimental setup.

An exploratory kaonic deuterium measurement was performed by alternating deuterium and hydrogen targets in the SIDDHARTA experiment at DAFNE [25].

In figure 6 a sketch of the experimental setup is shown. The back-to-back correlated charged kaon pair (K^+K^-) emitted from the ϕ(1020) decay (with a branching ratio of about 50%) was detected by the two scintillators mounted above and below the beam pipe at the interaction point ("kaon detector"'). The charged kaons were stopped in the gas, after passing through the scintillator and degrader. X-rays from kaonic atoms were detected by large-area (1cm^2) Silicon Drift Detectors (SDDs), installed around the target cell, with a total area of 144 cm^2.

Further development of large area Silicon Drift Detectors for X-ray spectroscopy was based on the SIDDHARTA SDDs. The new SDDs have a much better ratio of active to total area ~80% (compared to ~20%) and could be closer packed around the target.

3 The proposed experimental setup

The proposed kaonic deuterium experiment will use the excellent features of the K1.8BR kaon beam line together with the K1.8BR spectrometer. We plan to upgrade the spectrometer with a cryogenic deuterium target surrounded by SDDs with a total area of 246 cm^2 (380 single elements) for X-ray detection.

3.1 The setup at the K1.8BR spectrometer

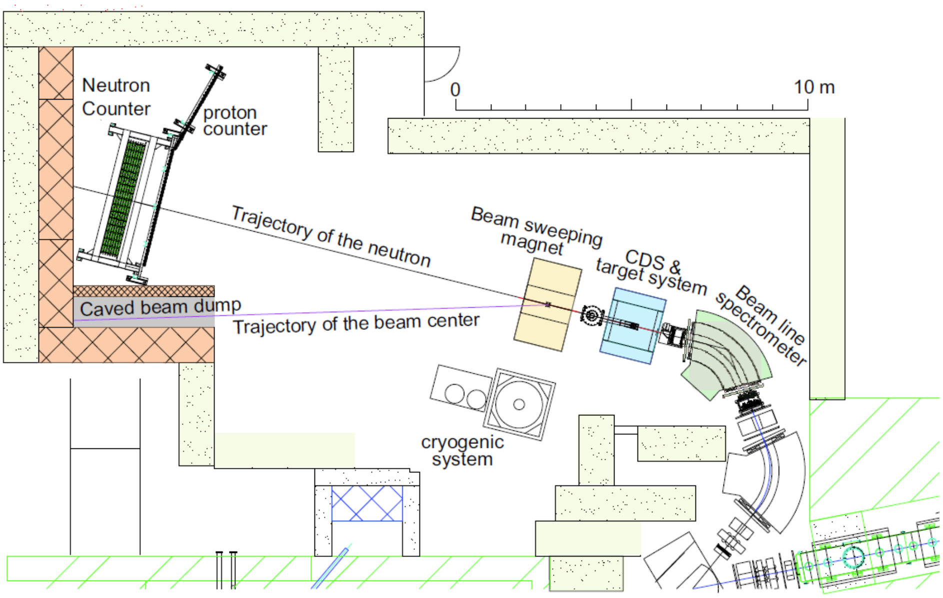

Figure 7: The J-PARC K1.8BR spectrometer. The setup consists of a beam line spectrometer, a cylindrical spectrometer system (CDS), a beam sweeping dipole magnet, a caved beam dump equipped with beam monitor hodoscopes, a neutron counter made of an array of plastic scintillation counters equipped with charged veto counters and a proton counter hodoscope.

The K1.8BR multi-purpose spectrometer [32] (see figure 7) has quite a unique features for our needs, namely a large acceptance cylindrical spectrometer system (CDS), consisting of a cylindrical drift chamber (CDC) for charged particle tracking, essential for efficient background reduction for the proposed study of kaonic deuterium X-rays. The cylindrical drift chamber, with a diameter of 1060 mm and length of 950 mm, is surrounded by a cylindrical detector hodoscope (CDH) to trigger on decay particles.

These parts of the experimental setup will be utilized for the proposed experiment - to be upgraded with a cryogenic target system and a novel X-ray detector system with a total area of 246 cm^2, having excellent energy resolution (better than 150 eV at 6 keV) and improved timing (below 40 ns).

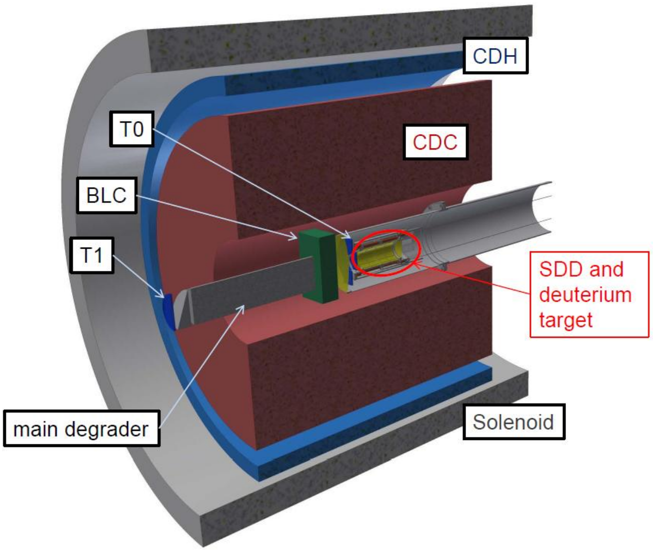

Figure 8: Sketch of the proposed setup for the kaonic deuterium measurement

The proposed setup (figure 8) will allow the tracking of the incoming kaons with segmented plastic scintillators, used as well as start counters (T1, T0) and the beam line chamber (BLC). The charged particles produced due to kaon absorption on the nucleus will be tracked by the large cylindrical drift chamber (CDC), while the cylindrical detector hodoscope (CDH) is used as the trigger in coincidence with the start counters (T1, T0).

*The **excellent tracking capability of E15** is essential for the efficient background suppression as described in the next paragraph (Monte Carlo studies).*

3.2 New Silicon Drift Detectors (SDDs)

We plan to use new SDD chips, which were developed in collaboration with Fondazione Bruno Kessler – FBK and Politecnico di Milano in Italy.

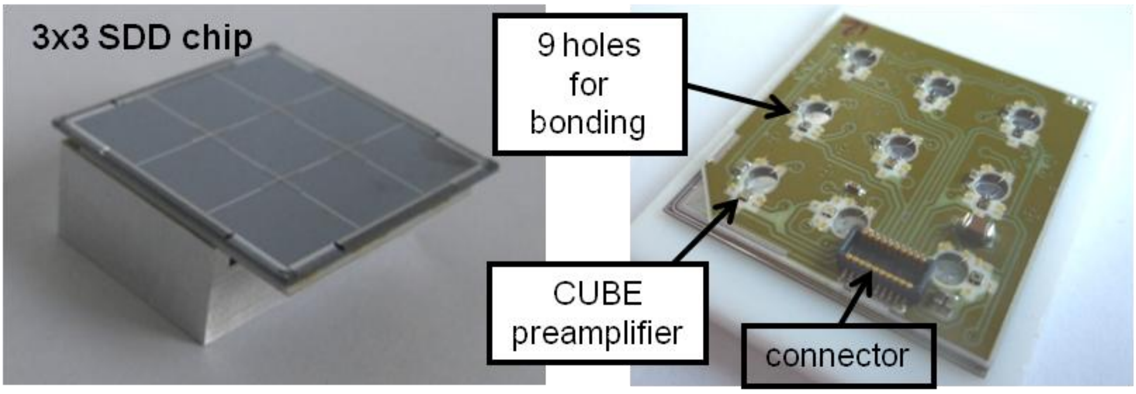

Figure 9: Monolithic array of 3x3 SDDs each 8x8 mm^2 (left); backside of the SDD array mounted on a printed circuit board with preamplifier chip (CUBE) for detector segment (right).

Monolithic arrays with 9 detector segments with a total area of 5.76 cm^2 (see figure 9) are ideally suited for the proposed experiment. For these SDDs, special preamplifier chips (CUBE), were developed.

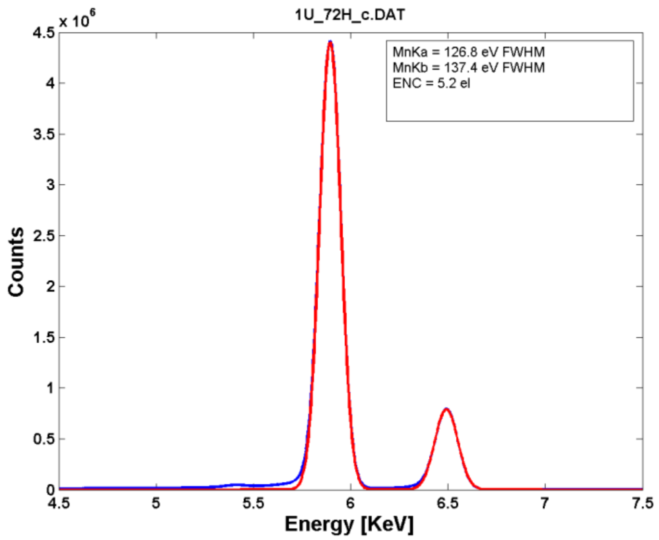

Figure 10: Test of a single cell at a temperature of 100 K, measured for 72 hours using a Fe-55 source. The MnK$_\alpha$ is seen with a FWHM of 127 eV.

First test measurements were performed successfully. For example, a 72 hours stability test, performed at a SDD temperature of 120 K, achieved an energy resolution of 130 eV at 6 keV (see figure 10). The drift time at this working temperature was measured to be around 200 ns.

Further cooling of the SDDs below 30 K will allow a reduction of the drift time to below 40 ns, which is an essential improvement for a further suppression of the beam related background.

3.3 Cryogenic deuterium target and SDD mounting structure

The cryogenic target cell will be made of a 75μm Kapton body with a diameter of 65 mm and a length of 160 mm, with reinforcement structure made out of aluminium. In addition, the cooling and mounting structure of the SDDs is used, in addition, to reinforce the target cell in longitudinal direction. The working temperature of the target cell is around 25 K with a maximum pressure of 0.35 MPa. With these parameters, a gas density of 5% liquid deuterium density (LDD) will be achieved. Finally, 48 monolithic SDD arrays will be structured close together around the target, with a total area of 246 cm^2 containing 380 readout channels (see figure 11).

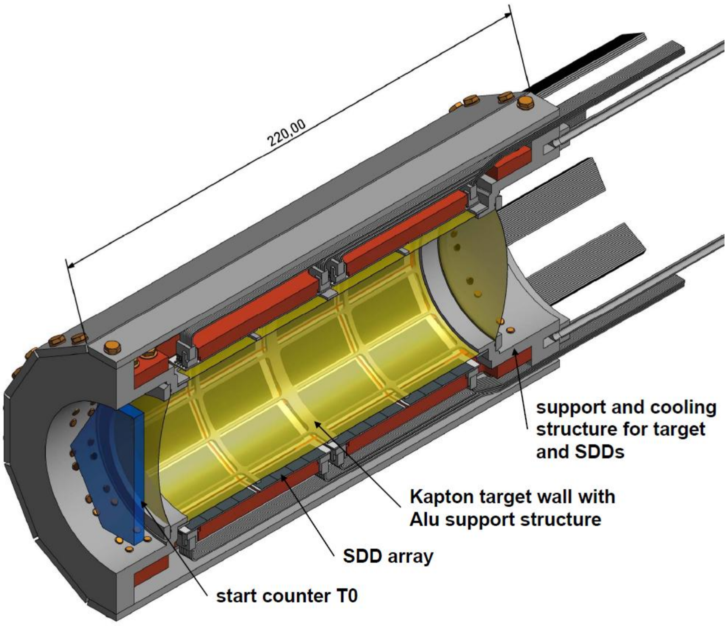

Figure 11: Design of the cryogenic target and X-ray detector system. The target cell, with a diameter of 65 mm and a length of 160 mm, is closely surrounded by SDDs, about 5 mm away from the target wall.

In summary, the recently developed SDDs attached to CUBE preamplifier chips are essential for the proposed experiment. These SDDs allow a compact design with the possibility to build a device having an ***excellent ratio of active to total area of 80%****, which allows a high packing density around the target cell to cover a large solid angle of about* 2π*. The additional feature of these SDDs is their* ***timing capability below 40 ns****, which is important to attain necessary asynchronous background reduction.*

4 Monte Carlo studies, beam time estimation

4.1 Degrader optimisation, kaon stopping distribution

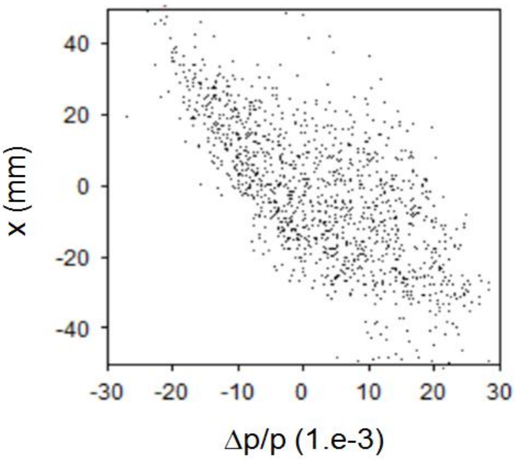

Figure 12: Momentum deviation versus lateral position

The kaon beam properties were taken from a measurement at the K1.8 BR in June 2012 with a kaon momentum of 1000 MeV/c (see figure 12).

For the use as a kaon degrader several materials (carbon, polyethylene and iron) were compared in the simulation. The highest stopping rates were obtained with a carbon degrader of about 40 cm thickness.

In table 3 the optimised results for the carbon degrader thicknesses are summarised for gas and liquid targets. Kaons with a central momentum of 700 MeV/c were assumed in the simulation. A prism shaped additional degrader was used to compensate the position dependence of the momentum (see figure 12).

degrader thickness [cm]	kaon target stops per beam kaon (x10^{-3})	target density
40	0.31	0.03
40	0.50	0.05
39	9.5	1

Table 3: Kaon stopping density in gaseous and liquid targets, optimised for carbon degrader. The target density is given relative to the liquid deuterium density (LDD).

In figures 13 the results of the kaon stopping optimisation of in gaseous and liquid deuterium targets are shown, respectively. The simulation to optimise the kaon stops in deuterium started with 7.10^6 K^- and a kaon momentum of 0.7 GeV/c.

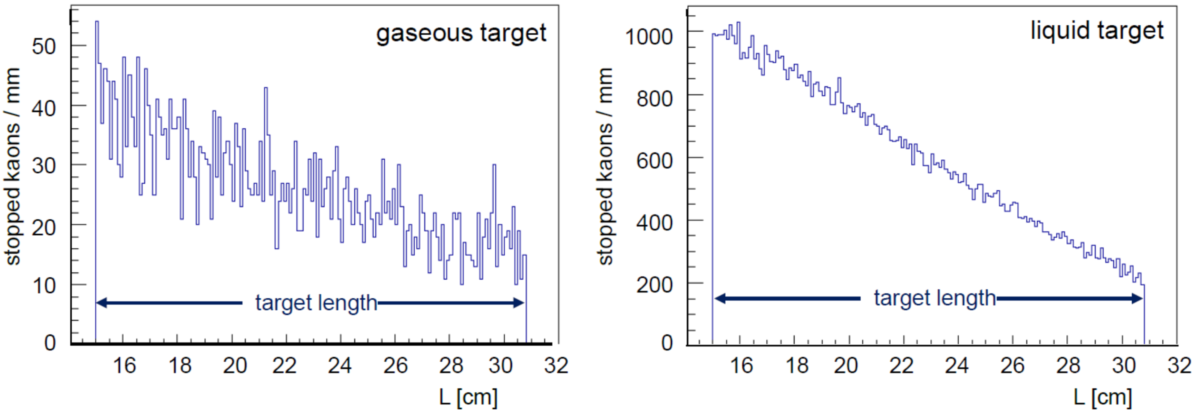

Figure 13: Kaon stopping distribution in the deuterium gas target with a density of 5% LDD (left), in the liquid deuterium target (right).

All further calculations are performed only for a gaseous target with a density of 5% LDD.

4.2 X-ray yields, cascade calculations

The most recent cascade calculations for kaonic deuterium are shown in figure 14, where the X-ray yields per stopped kaon for K_α-, K_β- and K_γ-transitions in a wide density range were calculated.

As input in our Monte Carlo simulation we used a K_α-yield of 0.1% for the gas targets and 0.01% for the liquid target, which are between the calculated values of Koike [33] and Jensen [34].

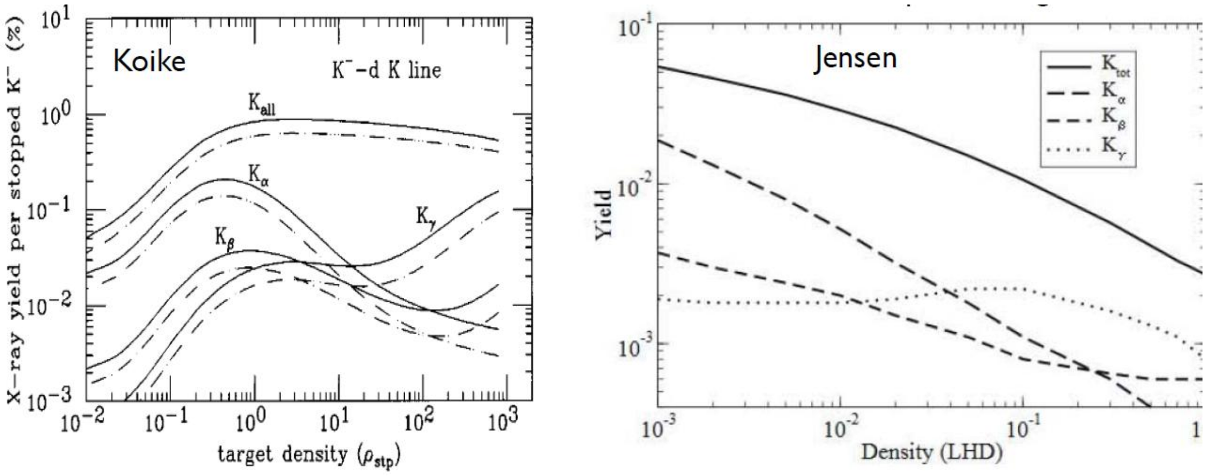

Figure 14: Kaonic deuterium cascade calculations, for the X-ray yield of K_α, K_β, K_γ and K_{tot}; figure from reference [33] (left) and from [34] (right).

4.3 Beam time estimation

We have simulated the kaonic deuterium X-ray spectrum, assuming a 30 kW beam power and 100 shifts ($1.0\cdot10^{8}$ K^{-} produced per shift assuming 80% duty cycle) using the new X-ray detector with an active area of 246 cm^2. The gaseous target density is 5% of LDD. The results of this calculation are summarised in table 4.

produced K^{-} per shift (80% duty cycle)	$1.0\cdot10^{8}$
numbers of K^{-} at beam counter (T1)	$5.8\cdot10^{6}$
trigger: T0⊗(charged particle in CDH)	$3.8\cdot10^{6}$
number of gas stops	$5.0\cdot10^{4}$
total synchronous BG per keV at 7 keV	$1.2\cdot10^{4}$
synchronous BG per keV at 7 keV, with fiducial cut and charged particle veto	30
asynchronous BG per keV at 7 keV	10
detected Kα events for a yield Y(Kα)=0.1%, with fiducial cut and charged particle veto	10

Table 4: Simulated values for synchronous background and the Kα transition X-rays yield. For the asynchronous background the adapted estimation of E17 is used. Background and signal are calculated for an active SDD area of 246 cm^2.

The yield ratios of the K_α:K_β:K_{total} transitions were taken from the kaonic hydrogen data, with an assumed K_α yield of 10^{-3} for the gaseous target. For the strong interaction induced shift and width, theoretical prediction were used:
shift = – 800 eV and width = 750 eV (see table 1).

The simulated spectrum for the transition energies of kaonic deuterium atoms is shown in figure 15, using the vertex cut method (successfully used with E570 at KEK and planned as well for E17 at J-PARC) with a defined volume inside the target (5 mm away from the walls), and a charged particle veto for tracks passing through or nearby SDDs.

For a gas density of 5%, the estimated signal to background ratio (integral) is 1:4 (see figure 15). Fitting a set of simulated data, we extracted the shift and width with a precision of 60 eV and 140 eV, respectively, which is comparable with the SIDDHARTA result of $K^{-}p$. In table 5 the fit results for gas target conditions are summarised.

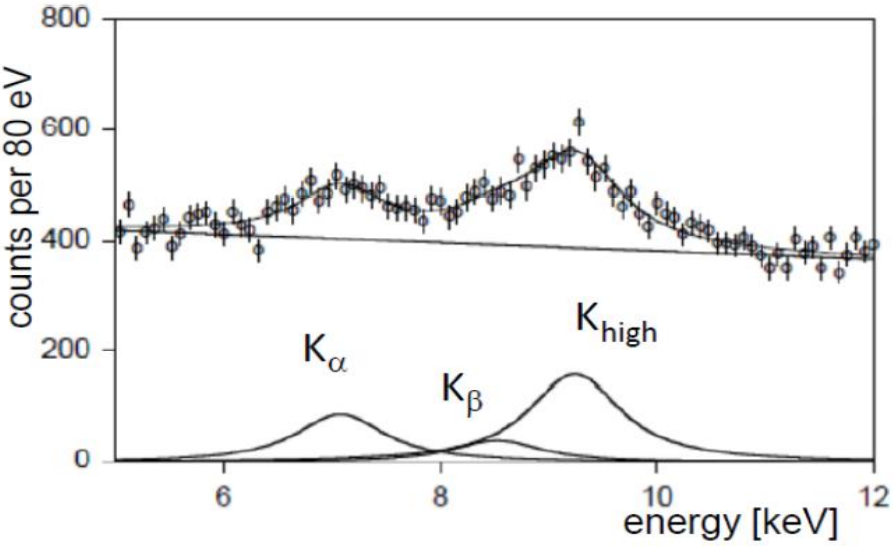

Figure 15: Simulated kaonic deuterium x-ray spectrum, assuming a 30 kW beam power, 100 shifts of data taking and a detector area of 246 cm^2*. Demanding an appropriate* K^- *signal on the beam counter after the degrader and using additionally a vertex cut (fiducial volume 5 mm off the walls) as well as the charged particle veto for tracks passing SDDs.*

density rel. to LDD	events for 33 days	Signal/BG	shift error [eV]	width error [eV]
0.05	1000	1:4	56	139

Table 5: The signal to background ratio is calculated from the sum of K_α *events divided by the sum of the background events in a region corresponding to the FWHM of the* K_α *peak. The simulated kaonic deuterium X-ray spectra were fitted and the precision in the determination of the shift and width are displayed in the last two columns.*

5 Beam time request

The X-ray detector for the proposed experiment will be newly build and used for the first time in a hadron machine environment. Therefore we ask for 12 shifts to optimize the stopping of kaons in the gas target and for the X-ray detector commissioning with hydrogen gas, which will allow in addition an important test of the background conditions to be compared with the simulations. The test with hydrogen should result in a similar data set as achieved with SIDDHARTA, and will allow for further reduction of the error in the determination of the K^-p scattering length.

After completion of the detector commissioning, we would like to request beam time for the physics run to measure the X-ray transition energies to the ground state of K^-d atoms. According to estimation done in the previous paragraph we will detect 30 Kα X-rays per day for a gaseous target (5% LDD) at the K1.8BR beam line with $3{\cdot}10^8$ K^- produced per day (for 30kW available beam power). For these numbers we have taken into consideration a duty factor of 80 % due to unavoidable stops of data taking due to maintenance of target etc.

The goal of the experiment will be to collect 1000 Kα events, which allows us to determine the ground state shift and width of K^-d atoms to a precision of 60 eV (for an assumed shift of – 800 eV) and 140 eV (assumed width of 750 eV), respectively. The requested beam time is therefore 100 shifts.

In summary, the requested beam time will be as follows:

- **Phase1:** Study and optimisation to stop the K^- beam in the gaseous target and detector commissioning. We would like to request **12 shifts (4 days)** with a proton beam intensity of 30 kW.
- **Phase 2:** Physics run with a proton beam intensity of 30 kW, producing $1.0{\cdot}10^8$ K^- per shift. We would like to request **100 shifts (33 days)** to reach the required precision in the determination of shift and width of K^-d atoms of 60 eV and 140 eV, respectively.

6 Cost estimation

The detector for X-ray spectroscopy and the cryogenic target system will be developed and build by the groups of LNF, Politecnico di Milano and SMI (a detailed cost estimation for the X-ray detector and target is listed in table 5).

To perform the proposed experiment the already existent E15 apparatus (spectrometer and DAQ) will be used as well as the refrigerator system of E31. But the running cost for the experiment (chamber gas, electronics modules, etc.) and local expenses will be needed, which will be covered by the RIKEN budget.

Item	Cost [€]	source
50 SDD arrays	50.000,- 75.000,-	Austrian Science Fund, SMI LNF-INFN
Cube-preamplifier and assembly	30.000,-	Politecnico di Milano
Read-out electronics	30.000,- 25.000,-	Politecnico di Milano LNF-INFN
DAQ	50.000,-	LNF-INFN
Cryogenic target	25.000,-	SMI
Vacuum chamber	15.000,-	SMI
Running costs E15 detector and local expenses	10.000,-	RIKEN Nishina Center

Table 5: Cost estimation

7 Conclusion

We have shown that for a 30 kW proton beam power with a momentum of 700 MeV/c about $3 \cdot 10^8$ K^- per day can be expected. Assuming this kaon intensity and rejecting the kaon correlated background using various cuts, especially a fiducial volume cut and a charged particle veto it will be possible to achieve a signal to background ratio of 1:4 for the kaonic deuterium K_α-line with a target gas density of 5%. The asynchronous background will be efficiently reduced due to the unprecedented timing resolution of the new SDD (< 40 ns).

We plan to start with **a commissioning phase of 12 shifts** with gaseous hydrogen to optimize the yield of kaons stopped in the target and to prove the background suppression scheme, mainly due to the excellent particle tracking probability of the CDC and the charged particle veto.

For **kaonic deuterium data taking we need 100 shifts** of beam time, using a gas density of 5% LDD. 1000 Kα events will be collected, which allows a determination of the strong interaction induced shift and width of the 1s state of kaonic deuterium with a precision of 60 eV and 140 eV, respectively, comparable to the precision obtained with SIDDHARTA for shift and width.

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