First application of a tungsten single-crystal positron source at the KEKB injector linac

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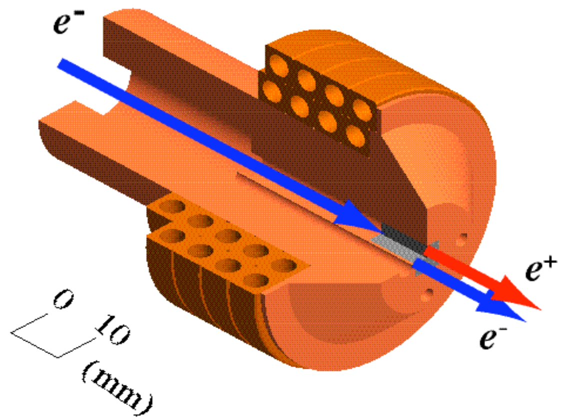
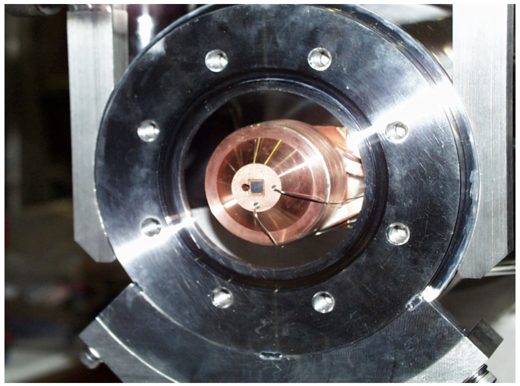
World's First Single Crystal Positron Source is Successfully Operated at the KEK B-Factory





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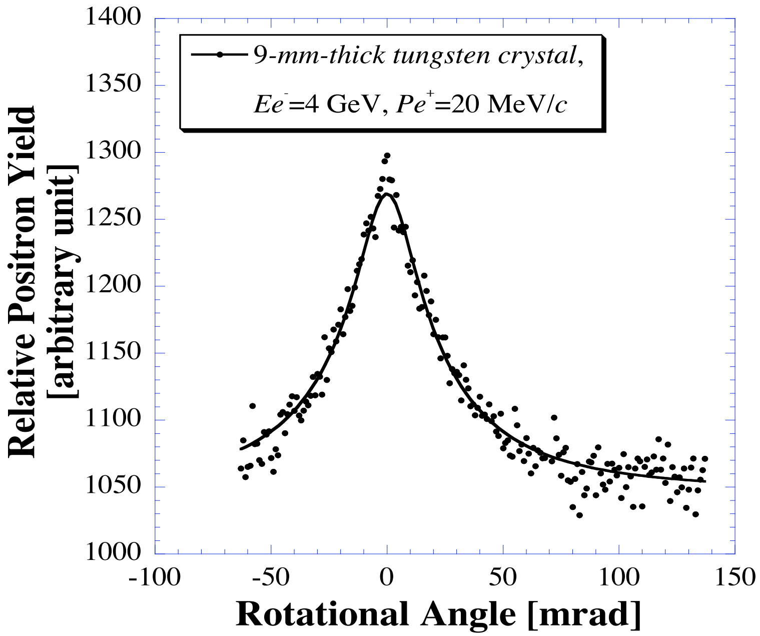
Abstract

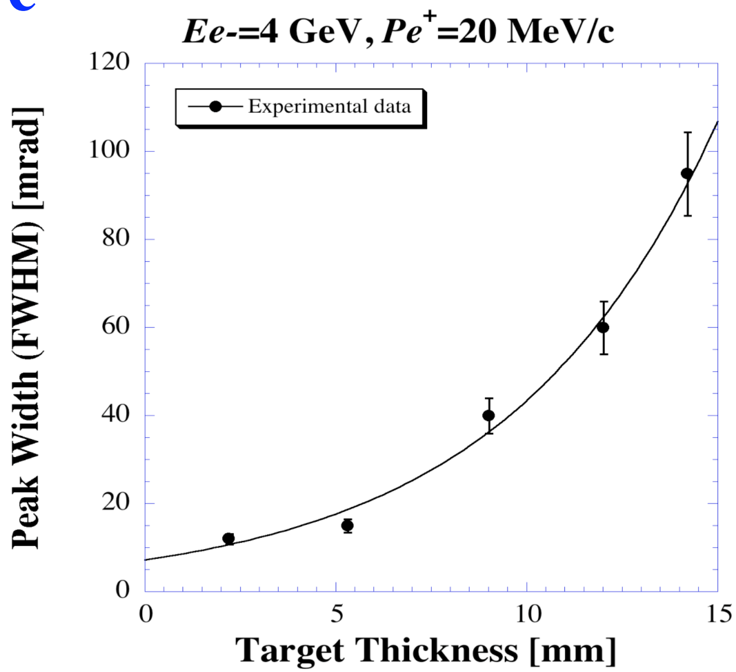
- A new positron-production target has been successfully employed for generation of the intense positron beam at the KEKB injector linac in September 2006. The target composed of a tungsten single-crystal (10.5 mm thick) is bombarded with 4-GeV incident electrons. The positrons are collected and accelerated up to 3.5 GeV in the succeeding sections. A conventional tungsten plate (14 mm thick) has been used previously, and the positron-production efficiency (PPE), the ratio of the number of positrons to the number of the incident electrons, was 0.20, and the crystal target increased to 0.25. The increase of the PPE has boosted the positron intensity to its maximum since the beginning of KEKB operation. Now this new positron source is stably operating and is contributing to increasing the integrated luminosity of the KEKB B-factory.

Introduction

- **In order to achieve high luminosities, positron sources must be boosted towards next generations of B-factories and e^+e^- linear colliders.**
- **Conventional heavy-metal targets limit to increase the beam power of primary electron beams due to the allowable heat load on the target.**
- **Crystal-assisted positron source is one of the bright schemes for high-intensity e^+ production.**
- **A new crystal-assisted positron source was first proposed by Chehab (IPNS), *et al.* in 1989.** (R. Chehab, *et al*., PAC'89, Chicago, IL, USA, Mar. 1989, p.283)
- **Yoshida, *et al.*, demonstrated a clear enhancement of the e+ yield in a tungsten crystal target using a 1.2-GeV electron beam.** (K. Yoshida, *et al*., Phys. Rev. Lett. 80, 1437, 1998)

Previous Experimental Results: Rocking Curves (tungsten crystal targets, crystal axis <111>) at Ee-= 4 GeV *and Pe+=* 20MeV/c

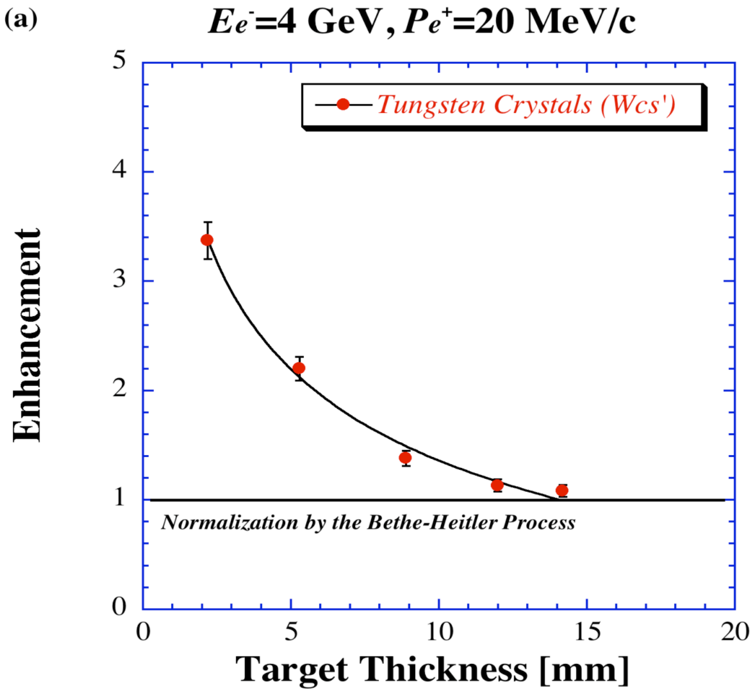


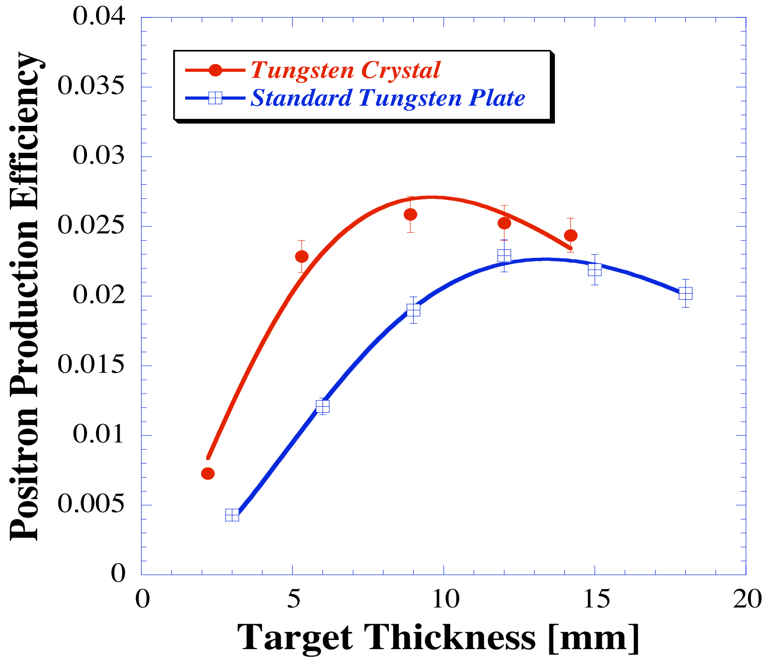


· ***(Left)*** Variations of the positron yield as a function of the rotational angle (rocking curve) of the crystal target. The broad peak width is mainly due to *multiple scattering* in tungsten crystal.

· ***(Right)*** Variations of the peak width (FWHM) as a function of the target thickness. The peak width is ~40 mrad (FWHM) for the 9-mm-thick tungsten crystal at 4 GeV *(see T.Suwada, et al., presented at LINAC'06, Knoxville, TN, US, Aug. 21-25, 2006).*

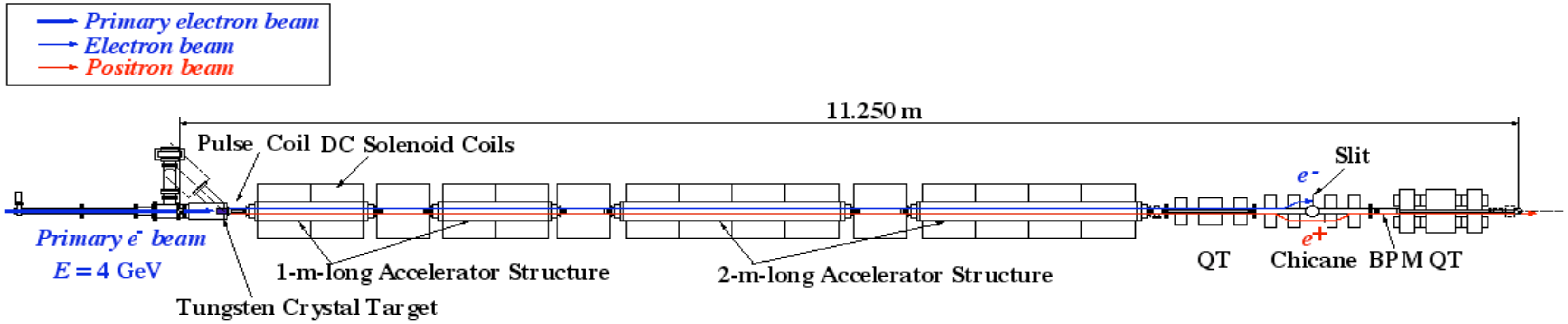
Previous Experimental Results: Positron production enhancement and target-thickness optimization at Ee-= 4 GeV and Pe+= 20MeV/c





· ***(Left)*** *Variations of the positron-yield enhancement as a function of the target thickness. The enhancements decrease with the increase of the target thickness, and at the crystal thickness of 14 mm, the positron yield almost agrees with that from a conventional* $4X_0$ *thick tungsten plate.* ***(Right)*** *Variations of the positron-production efficiency as a function of the target thickness. At the 9mm thick, the positron yield is ~26% larger than that for a conventional tungsten. The optimum thickness is reduced to be about 10 mm at 4 GeV due to the crystal effect while the optimum thickness of a conventional tungsten target is 14 mm.*

Layout of the KEKB positron source



Primary electron beam

· *The positrons are generated by a 4-GeV primary electron beam (~10 nC/bunch) impinging on a conventional tungsten target.*

· *The average beam power is 2 kW at a maximum repetition rate of 50 Hz.*

· *The typical transverse normalized emittances are 660 mm·mrad(horizontal) and 360 mm·mrad(vertical) on average.*

· *The typical beam size is 0.7 mm (rms) in radius.*

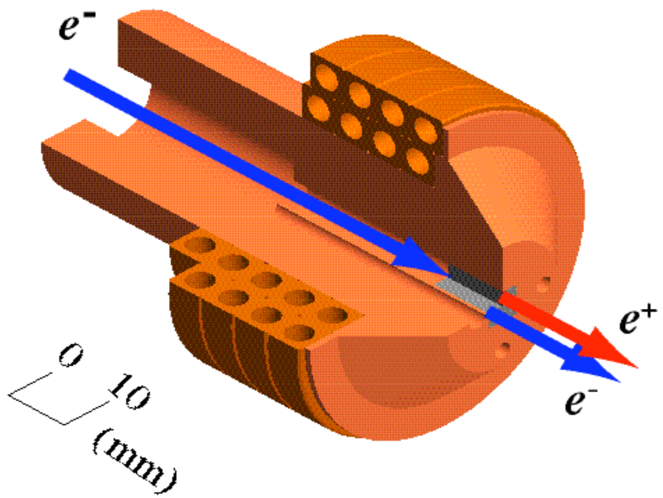
· *The horizontal (vertical) angular spread at the target is estimated to be 0.2(0.1) mrad, where these angular spreads need to be controlled within the critical angle for axial channeling (0.61mrad at 4GeV) in tungsten crystal.*

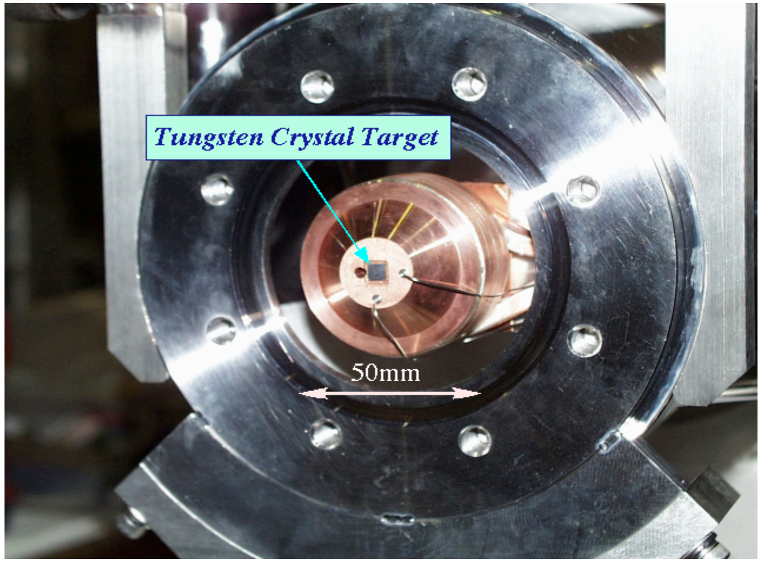
Positron capture section (Quarter-wave transformer)

· *It comprises a 45-mm-long pulse solenoid (2 T), an 8-m-long DC solenoid (0.4 T), and two 1-m-long and two 2-m-long acceleration structures.*

· *The electrons along with the positrons generated from the target are stopped by a positron/electron separator (chicane) comprised four rectangular magnets and a beam stopper at the center of the chicane (see A.Enomoto, et al., EPAC'92, vol.1,1992, p.524).*

Tungsten Crystal Target: Crystal target fabrication after post-machining



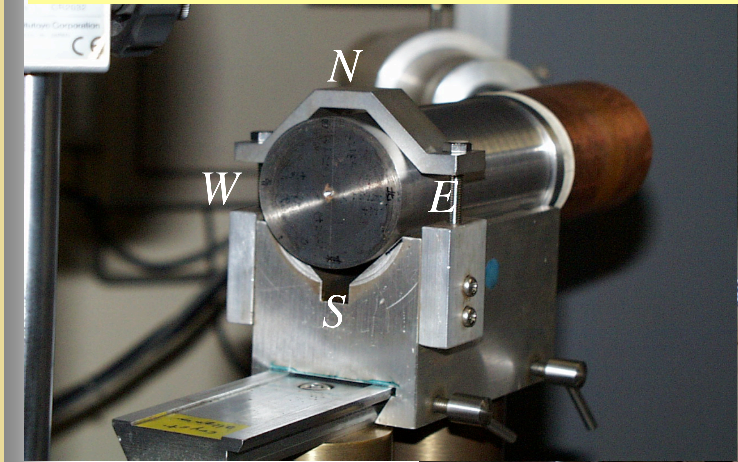


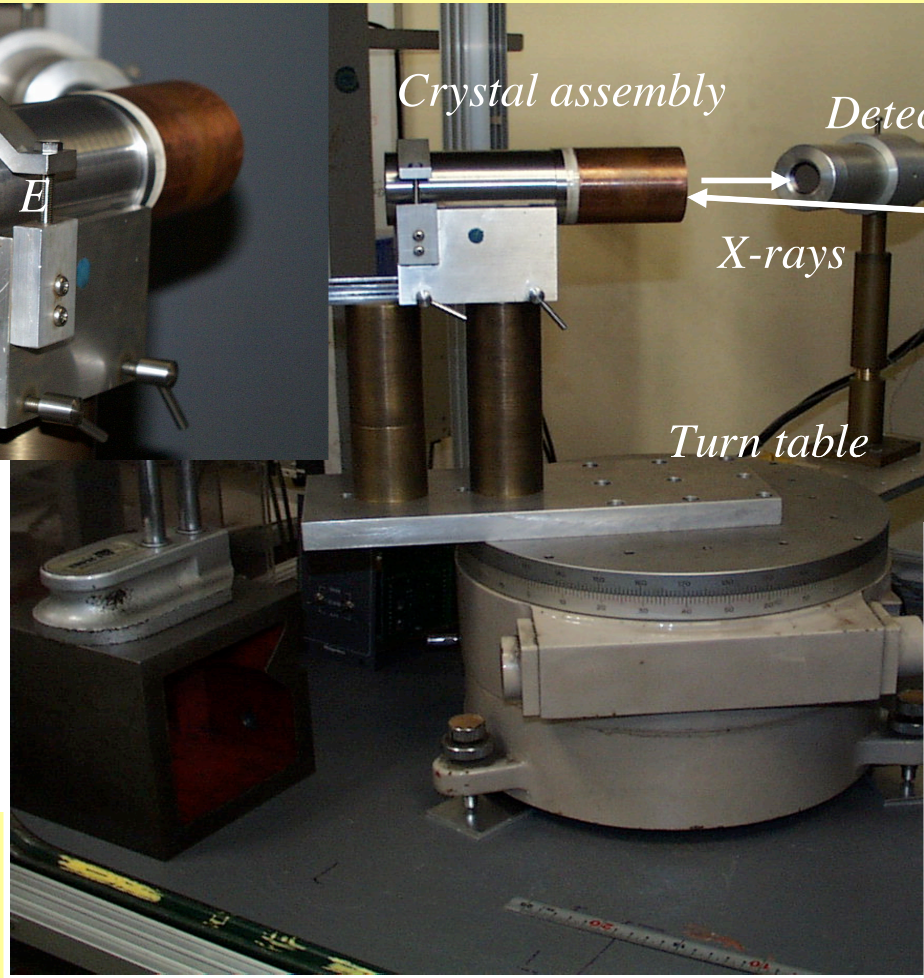
*(**Left**) Mechanical drawing of the target assembly. The tungsten crystal is fixed to the cylindrical copper body with a diameter of 50 mm for water cooling. The heat deposited on the crystal target is conducted through a cooling water channel (water flow1.5l/min) composed of a copper pipe (4mm in diameter). Electrons (blue arrow) impinge the tungsten crystal target and they are converted to the electrons (blue arrow) and positrons (red arrow).*

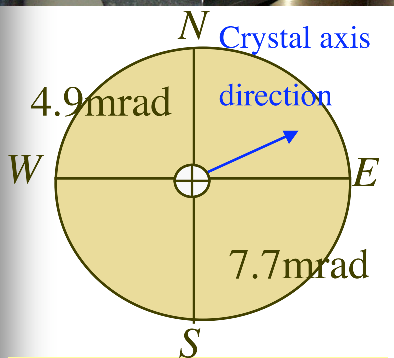
*(**Right**) Target assembly after the post-machining process installed in a vacuum chamber seen from downstream. Two thermocouples are mounted 7.5 mm away from the center of the tungsten crystal, and a small hole with a 3 mm diameter is penetrated through the copper body for the transport of the electron beam.*

Crystal target fabrication: Crystal axis measurement by an X-ray Bragg reflection

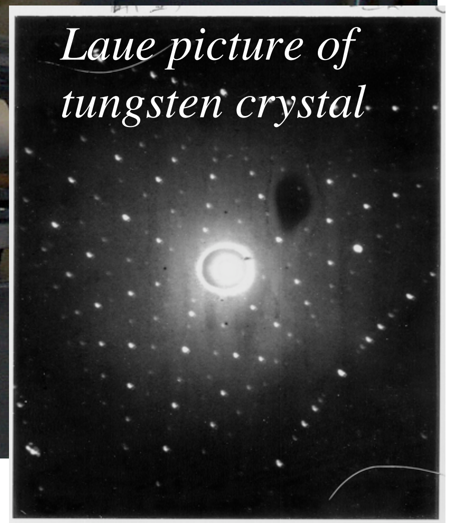
The target assembly itself was precisely machined in order to keep the precise alignment between the crystal axis and the central axis of the target assembly based on the crystal-axis measurement.



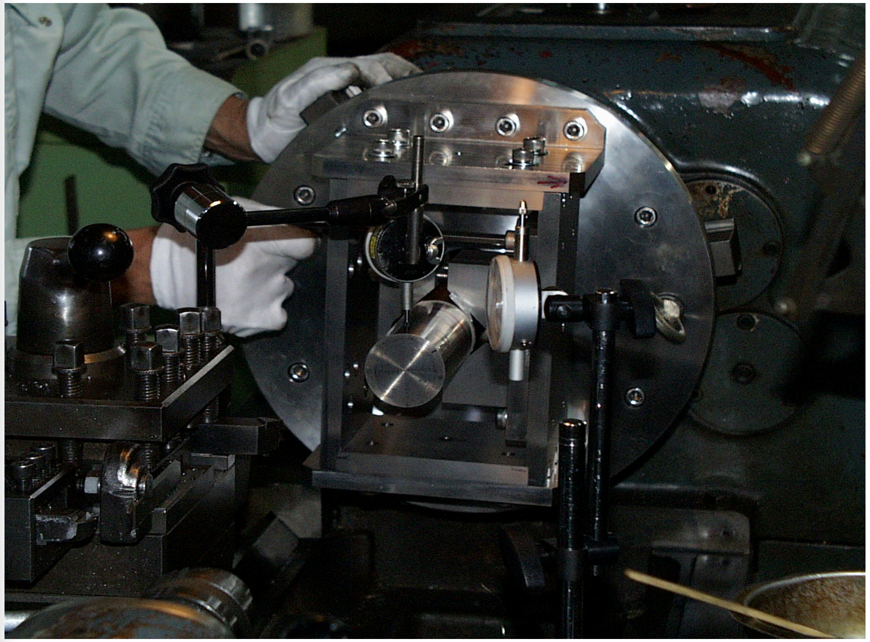


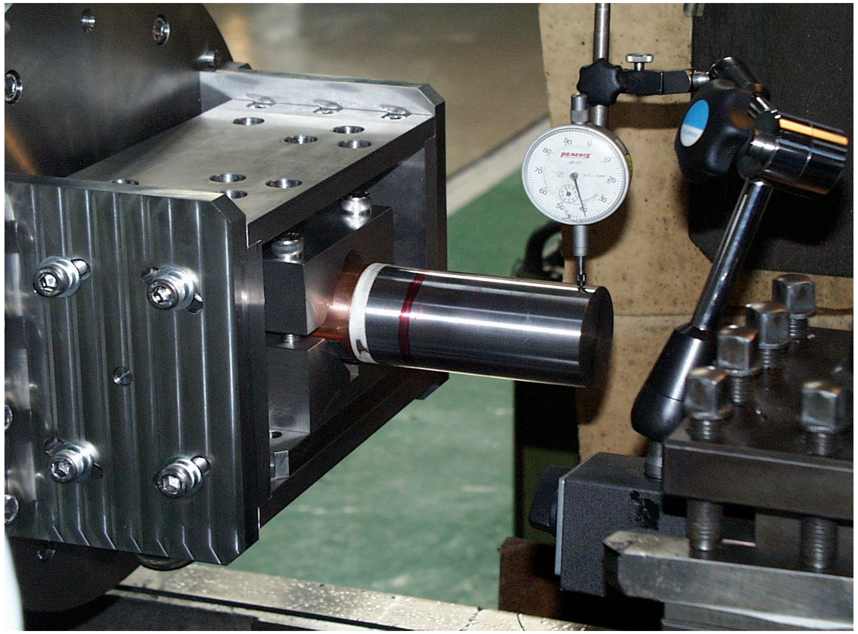


Inclination direction of the crystal axis to the central axis of the copper body



Crystal target fabrication: Fabrication process of the crystal target assembly machined by a lathe





· ***(Left)*** *Target assembly fixed at the center of a positioning jig seen from upstream. In this machining procedure, the relative inclination angles between the crystal axis and the central axis of the copper body are corrected based on the Brag reflection measurement results. First, the stainless-steel body was precisely machined by a lathe and finally the copper body was similarly machined.*

(Right) *Target assembly seen from sideways.*

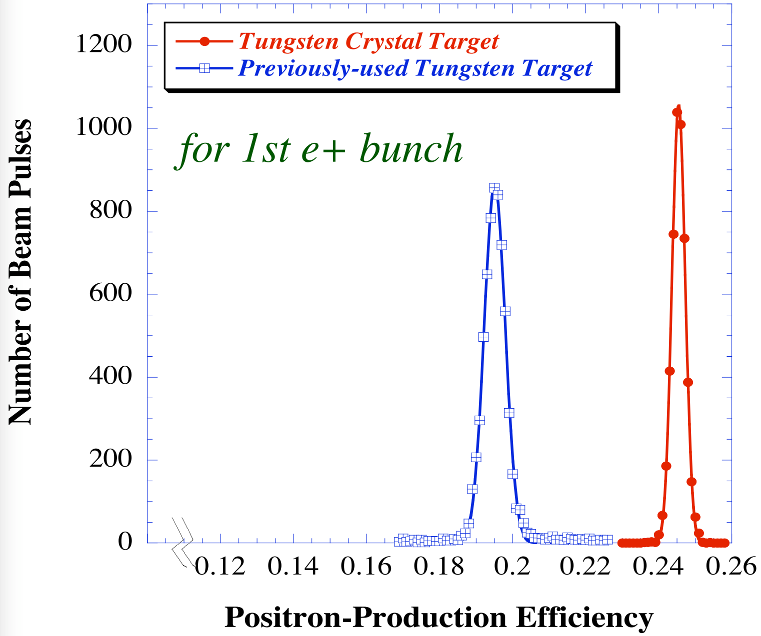
Alignment of the target assembly: Alignment and reproducibility tests at the installation of the target assembly into a vacuum chamber

Error estimation for each test items	*Reproducibility error*
Linear actuator in & out	*0.41 mrad*
Target chamber mounting on & off	*0.41 mrad*
Transportation test	*0.41 mrad*
Remounting of the mirror	*1.81 mrad*
Other systematic errors	*2 mrad*
X-ray axis-measurement	*±1 mrad*
In total	*±3 mrad*

· ***(Left)*** *Alignment procedure of the target assembly with a precise alignment telescope with an angular resolution of 0.5 mrad.*

· After this fundamental alignment procedure, further alignment tests were made in order to *check the reproducibility of the target alignment (a) with a linear actuator in and out (40 times), (b) with the target chamber mounting on and off (3 times), (c) the transportation test of the target chamber, and (d) the remounting test of an alignment mirror.*

Performance of the crystal target: Positron-production efficiency measurements

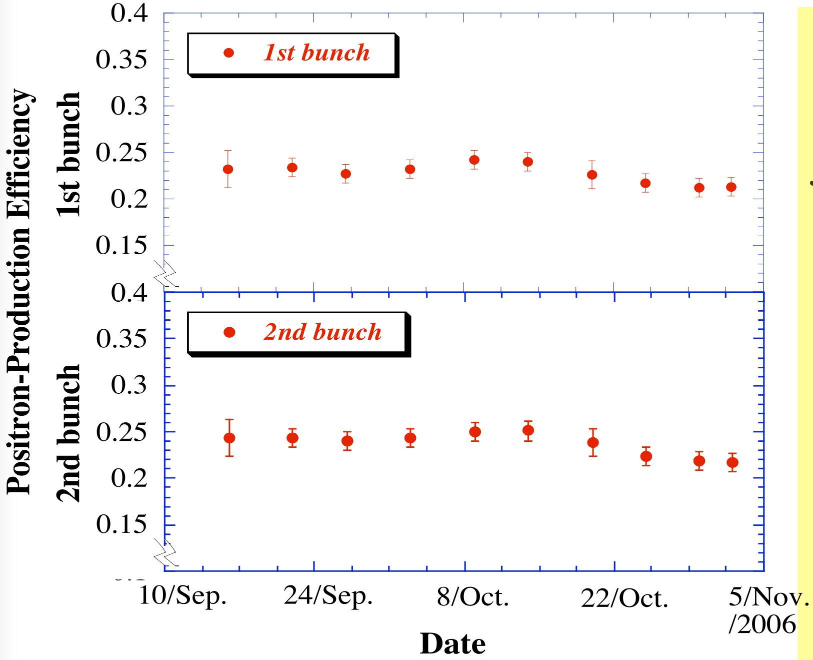


Positron-Production Efficiency
Results of Tungsten Crystal Target
PPE(1st)=0.25±0.01,
PPE(2nd)=0.26±0.01
Results of Previous Tungsten Target
PPE(1st)=0.2±0.01,
PPE(2nd)=0.2±0.01

· ***(Left)*** *Positron-production efficiencies (PPE) of the 1st bunch measured for each beam pulse. The data were obtained after adjusting the incident angles of the primary electron beam with upstream steering magnets. For the sake of comparison, the data of the previous tungsten plate (June 2006) were plotted. The solid lines are gaussian-function fits of the data. The PPE is defined by* Ne^+ / Ne^-*, where* Ne^+ *is the number of positrons captured in the positron capture section and* Ne^- *is the number of the primary electrons.*

· *The results show that the increase of the positrons is* 25 ±2% (28 ±2%) *for the 1st (2nd) bunch* on average. The results are consistent with those obtained in the previous experiments.

Performance of the crystal target: Operational performance



• **(Left)** *Time traces of the positron-production efficiencies of the two bunches averaged every five days after the start-up of KEKB operation in summer 2006.*

• *The emittance-measurement results of the positron beams are consistent with those obtained for the previously-used tungsten plate. This means that the transverse emittances are mainly determined by the acceptance of the positron capture section.*

• *The integrated electron flux hitting the crystal target has amounted to about 5.5×10*^{7} *nC/mm*^{2} *(average one-bunch charges of 7.7 nC/bunch at 4 GeV) for the KEKB two-month operation. No damage on the crystal structure was observed after the irradiation. Clear answers will be obtained in future operational experience of the KEKB.*

Normalized emittances of positrons

Horizontal

$\gamma\varepsilon_x$= 1440 ±40mm·mrad (1st),

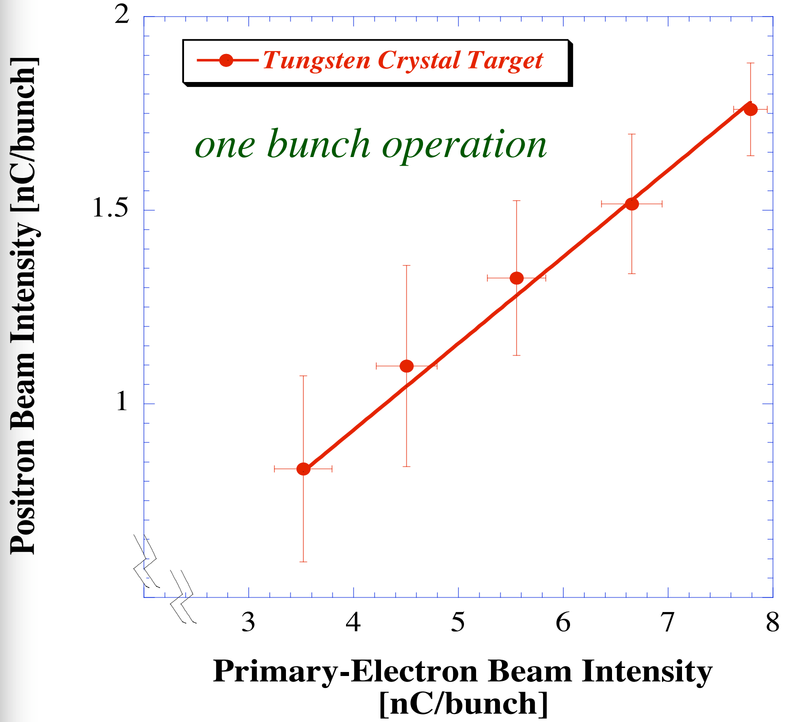
$\gamma\varepsilon_x$= 1500 ±80mm·mrad (2nd),

Vertical

$\gamma\varepsilon_y$= 1640 ±110mm·mrad (1st),

$\gamma\varepsilon_y$= 1740 ±60mm·mrad (2nd),

Performance of the crystal target: Linearity of the positron intensity to the primary-electron intensity

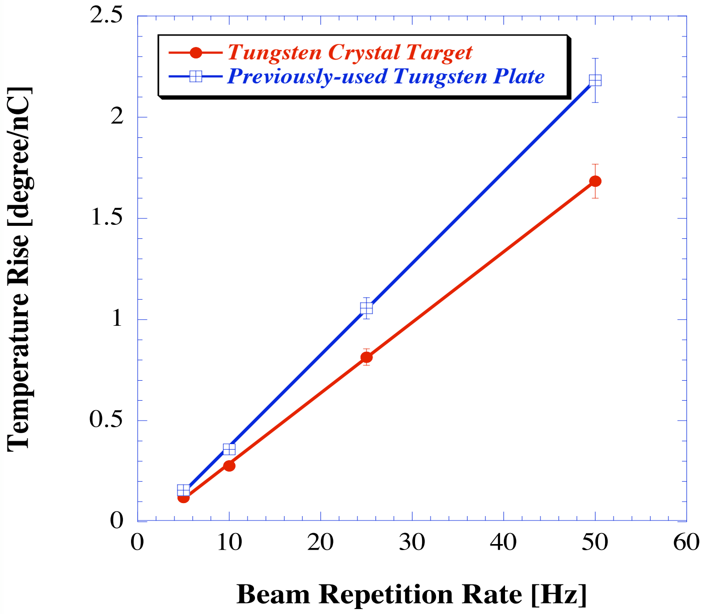


· ***(Left)*** *Positron beam intensity plotted versus the primary electron beam intensity in a bunch*. The solid line through the data indicates a linear-function fit of the data.

· The present results show that the positron yields increase linearly with the increase of the primary electron intensity without any abnormal behavior within the experimental errors.

The average instantaneous charges is 7.7 nC/bunch at 4 GeV.

Performance of the crystal target: Temperature-rise measurements



· ***(Top)*** *Variations of the temperature rise of the tungsten crystal target as a function of the beam repetition rate under one-bunch operation. In this figure the temperature rise is normalized by the average beam charges of the primary electron beam. For the sake of comparison, the data of the previously-used tungsten target are plotted.*

· The temperature rise was measured with two thermocouples mounted inside the copper body.

· The average temperature rise is ΔT~13.2^{o}C at a beam repetition rate of 50 Hz under one-bunch operation condition with an average bunch charge of 7.8 nC/bunch.

· The results show that the temperature rise of the crystal target changes linearly as a function of the beam repetition rate, and that the heat load normalized by the primary electron charges is clearly reduced by ~20% in comparison with the previously-used tungsten target.

· The measured heat loads are consistent with simulation results performed by Artru, *et al*. (X. Artru, *et al.*, Phys. Rev. ST Accel. Beams 6, 091003 (2003)).

Performance of the crystal target: Operational experiences

- *The new positron source has been stably operating without any significant reduction of the positron-production efficiency during two months.*
- *For long-term KEKB operation, it would be useful to apply a feedback control to stabilize the incident angles of the primary electron beam in the direction of the crystal target axis.*
- *The integrated electron flux hitting the crystal target has amounted to* $\sim 5.5\times10^{7}$ nC/mm^2.
- *As for the radiation damage effect, Artru et al. tested on a 0.3-mm-thick tungsten crystal placed in front of the SLC positron source up to the integrated electron flux of* 3.2×10^{8} nC/mm^2. *No damage to the crystal structure was found after this irradiation.*
- *We expect that the present tungsten crystal target can be used for one year at least without any serious radiation damage according to their results.*

Conclusions

- *We have successfully applied a new tungsten single-crystal target for generation of the intense positron beam at the KEKB positron source.*
- *The positron intensity increased by ~25% in comparison with that obtained from the previously-used conventional tungsten target.*
- *On the contrary, the heat load on the crystal target reduced by ~20%.*
- *The tungsten crystal target has boosted the positron intensity to its maximum since the beginning of the KEKB operation in 1999.*
- *This is a first application of the crystal target to high-energy electron/positron linacs.*
- *Useful information on radiation damage and stability of the crystal target will be obtained through KEKB operation.*
- *The present result encourages us to consider the application of crystal targets in the next generation of the B-factories and e^+e^- linear colliders.*