Positron-production experiment using Diamond and Si crystals in the KEKB 8-GeV injector linac

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Collaboration

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Motivation

- **High-intensity positron sources are required for future linear colliders and B-factories.**
- **Conventional methods using amorphous heavy metals limit to increase the intensity of primary electron beams due to the heat load on the target.**
- **New method using the processes of coherent bremsstrahlung (CB) and channeling radiation (CR) is one of the bright schemes for high-intensity e^+ production.**

Introduction

- **New method utilizing a crystal target was proposed by Chehab, *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)

Introduction (cont'd)

- **A series of e+ production experiments based on the new scheme has been continued,**

  ⇒by Yoshida(Hiroshima/KEK), *et al.*,

  using 1.2-GeV *e*- beam of the ES at KEK-Tana branch, 3-GeV *e*- beam at *e*+ station, and *e*- beam(<8GeV) at the end station of the KEKB injector linac.

  ⇒by Chehab(LAL), *et al.*,

  using 5-40 GeV secondary *e*- beam at CERN-SPS.

Introduction (cont'd)

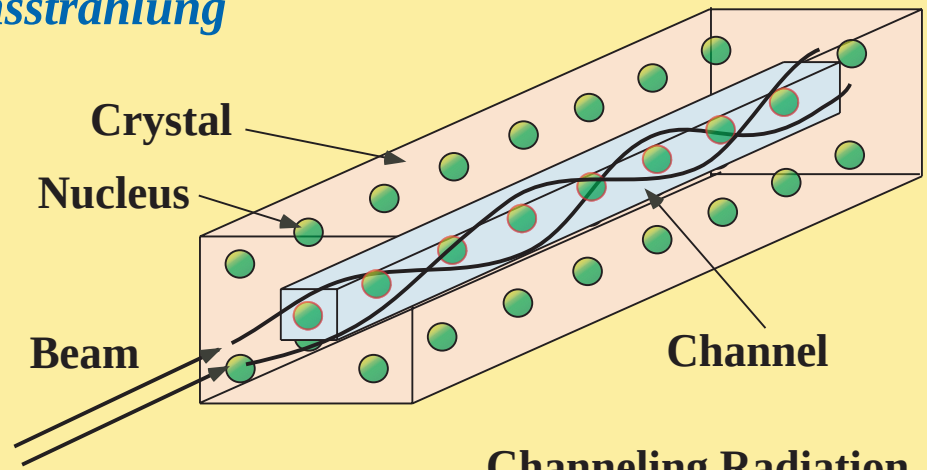
- **Theoretically unified treatment taking into account both processes of CR and CB has not yet been established on the simulation.**
- **More experimental data are expected to clearly understand the elementary physical processes of the CR and CB, and they are also required to develop the design of a real-type positron source.**

Historical View of the KEK Experiments

Month/Year			
May/1997	KEK Tanashi, ES	1.2	Crystal W (W_c) [1.2]
Apr, Jun/1998	KEK Tsukuba, Electron Linac	3	W_c [1.7] + Amor. W (W_a) [7]
Nov/1998	KEK Tanashi, ES	0.6, 0.8, 1	W_c [0.4, 1.2, 2.2], GaAs [0.36], Diamond[1.1]
Sep, Oct/2000	KEK Tsukuba, Electron Linac	8	W_c [2.2], W_c [2.2]+W_a [5, 10, 15]
Apr/2001	KEK Tsukuba, Electron Linac	8	W_c [2.2], W_c [9] W_c [9]+W_a [2, 4]
Sep/2001	KEK Tsukuba, Electron Linac	8	W_c [2.2], W_c [5.3], W_c [9] Combined targets(W_c +W_a)
Jan/2002	KEK Tsukuba, Electron Linac	4	W_c [2.2], W_c [5.3], W_c [9] Combined targets(W_c +W_a)
Aug-Sep/2002	KEK Tsukuba, Electron Linac	8	Si <110> 2.6, 30, 48 Diamond <110> 4.57 Combined (Si/Dia.+W_a)
Dec/2002	KEK Tsukuba, Electron Linac	8	Si <110> 10, 30, 48 Diamond <110> 4.57 Combined (Si/Dia.+W_a)

Channeling Radiation & Coherent Bremsstrahlung Processes

Physical processes for the channeling radiation and coherent bremsstrahlung



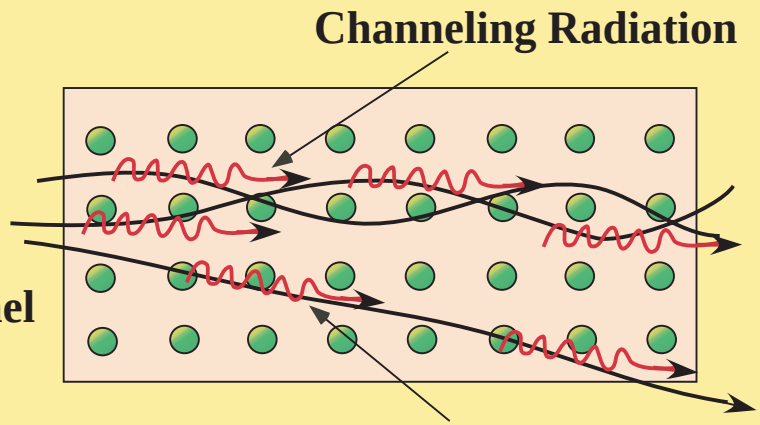
Critical Angle of Channeling Radiation

$F_c=(2U_0/E_b)^{1/2}$

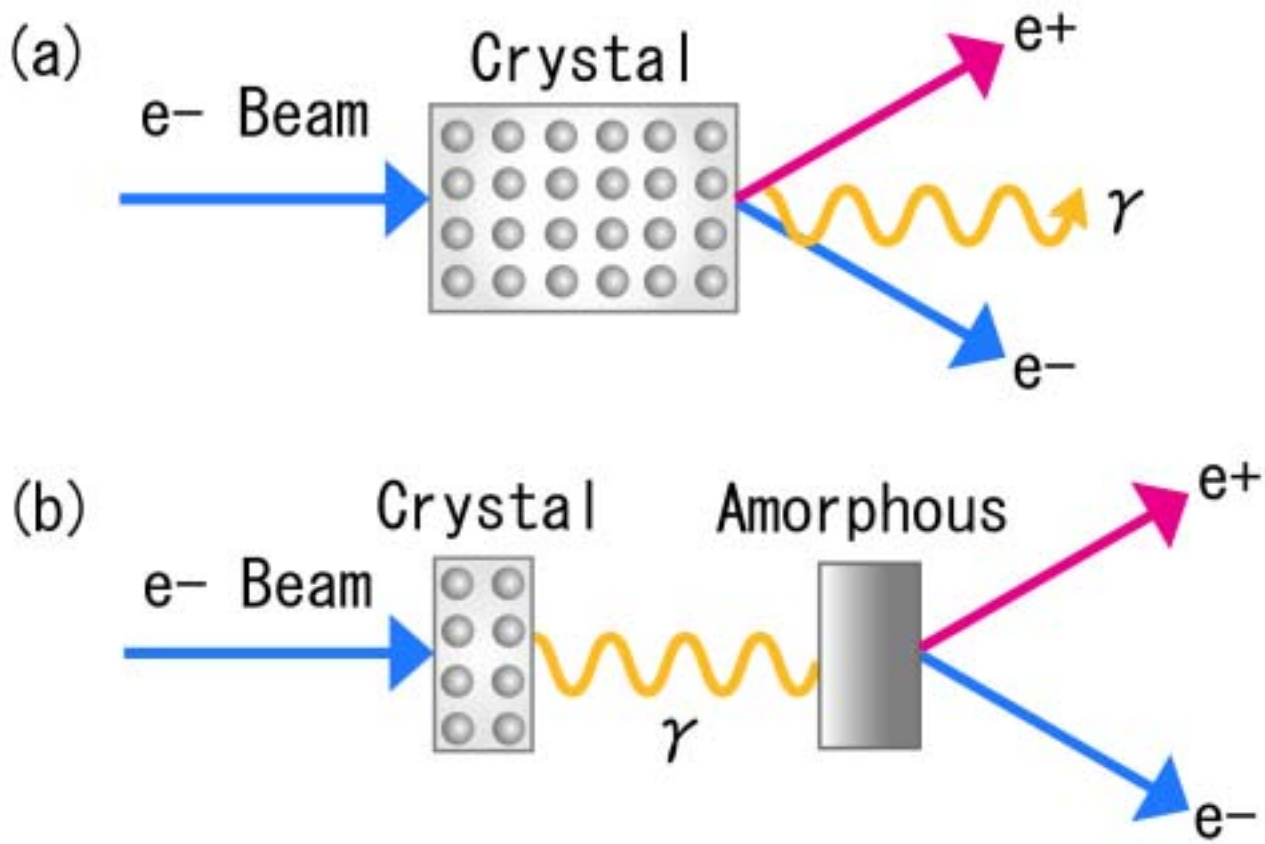
$\sim 0.43\text{mrad}@E_b=8GeV$

U_0:**Potential Energy of a Channel**

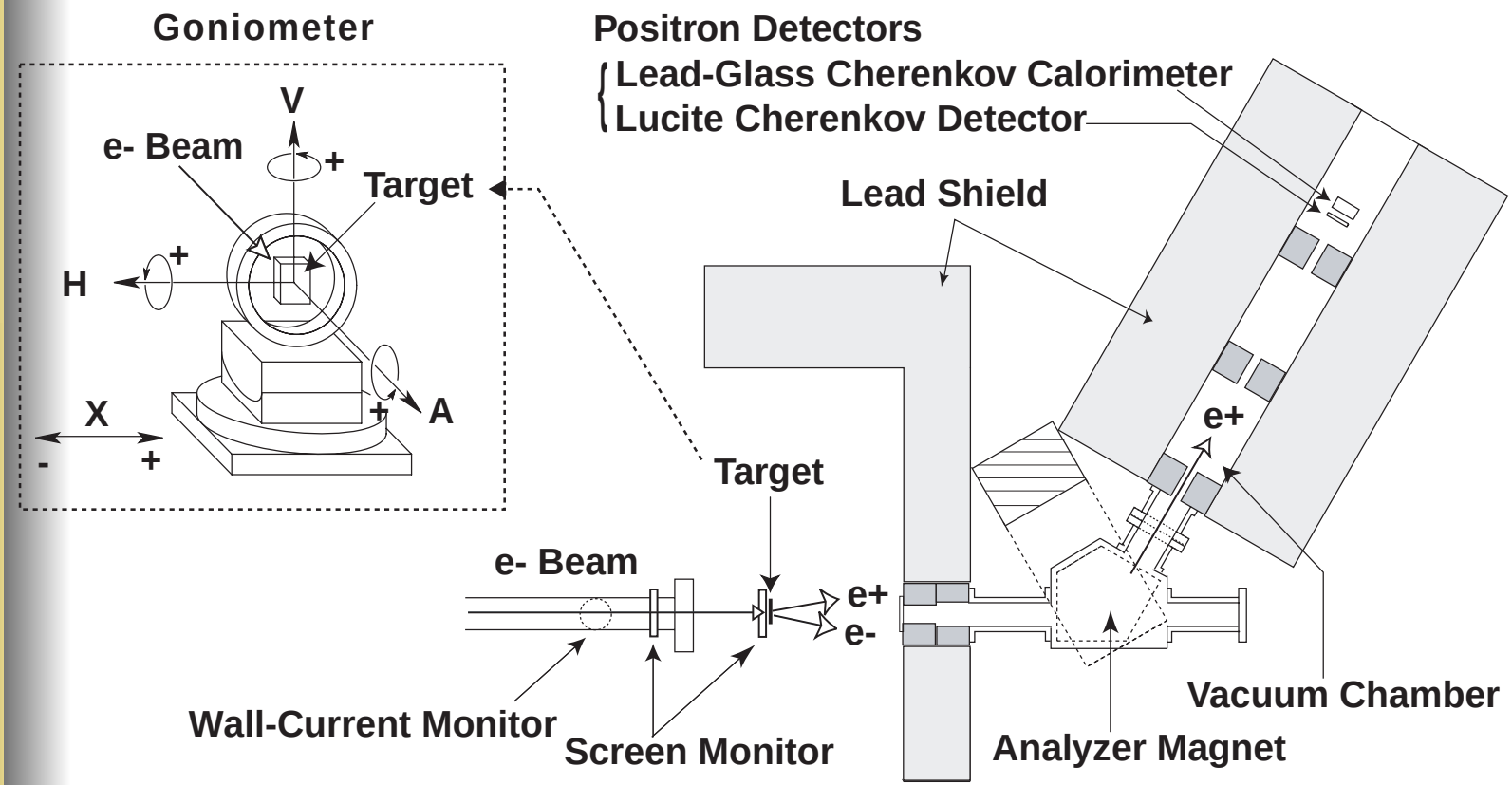
E_b:**Beam Energy**



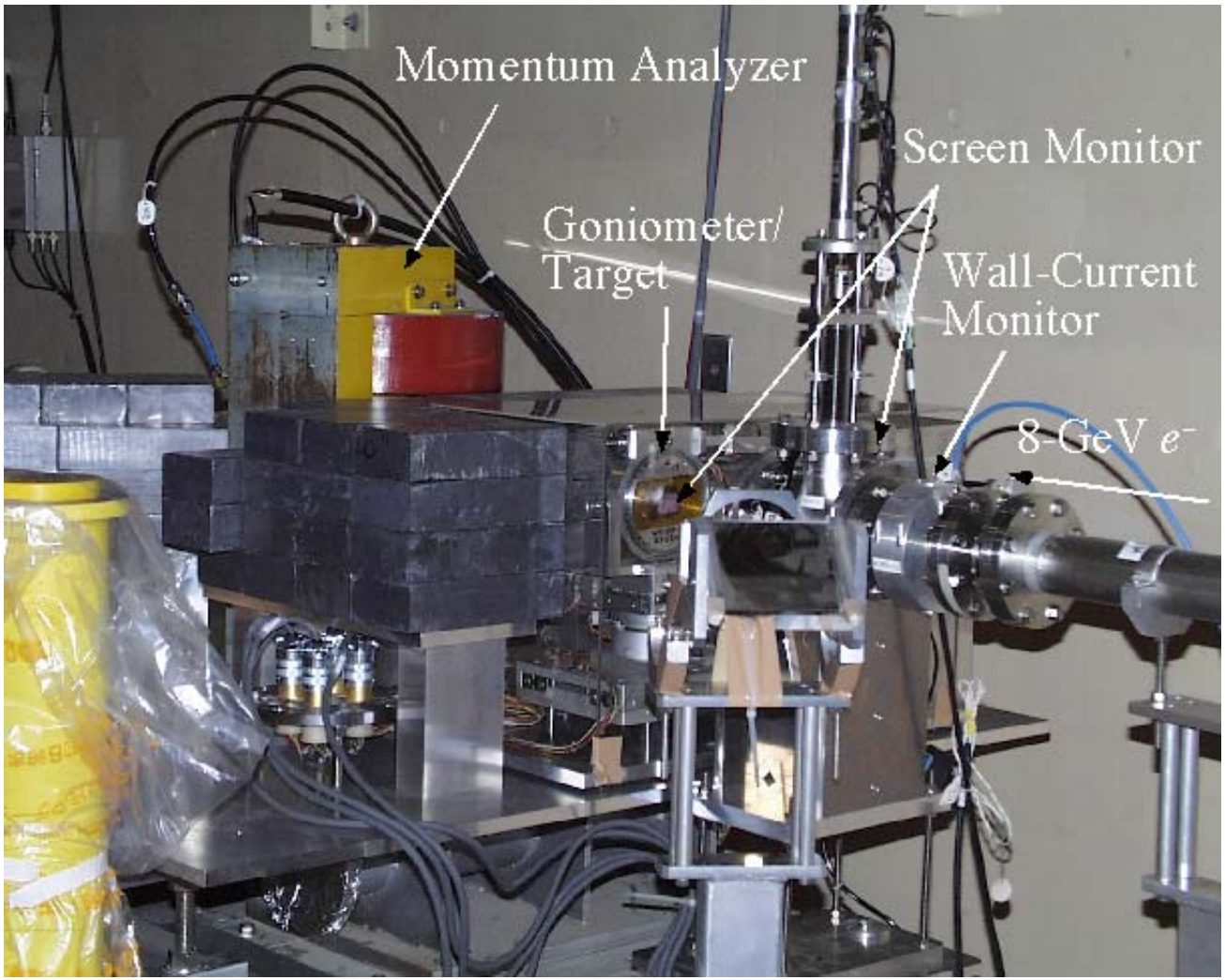
New Positron Production Schemes



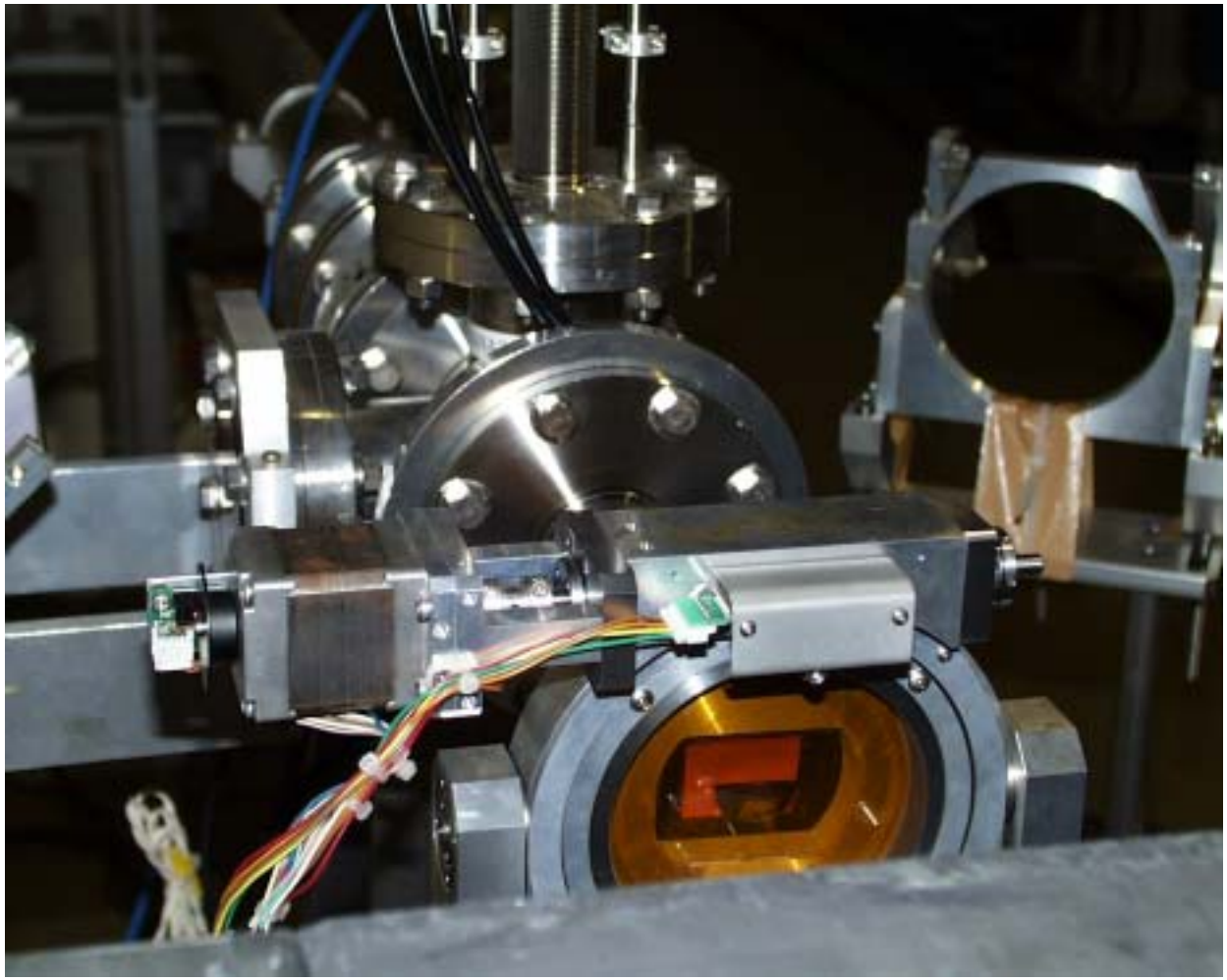
Experimental Setup



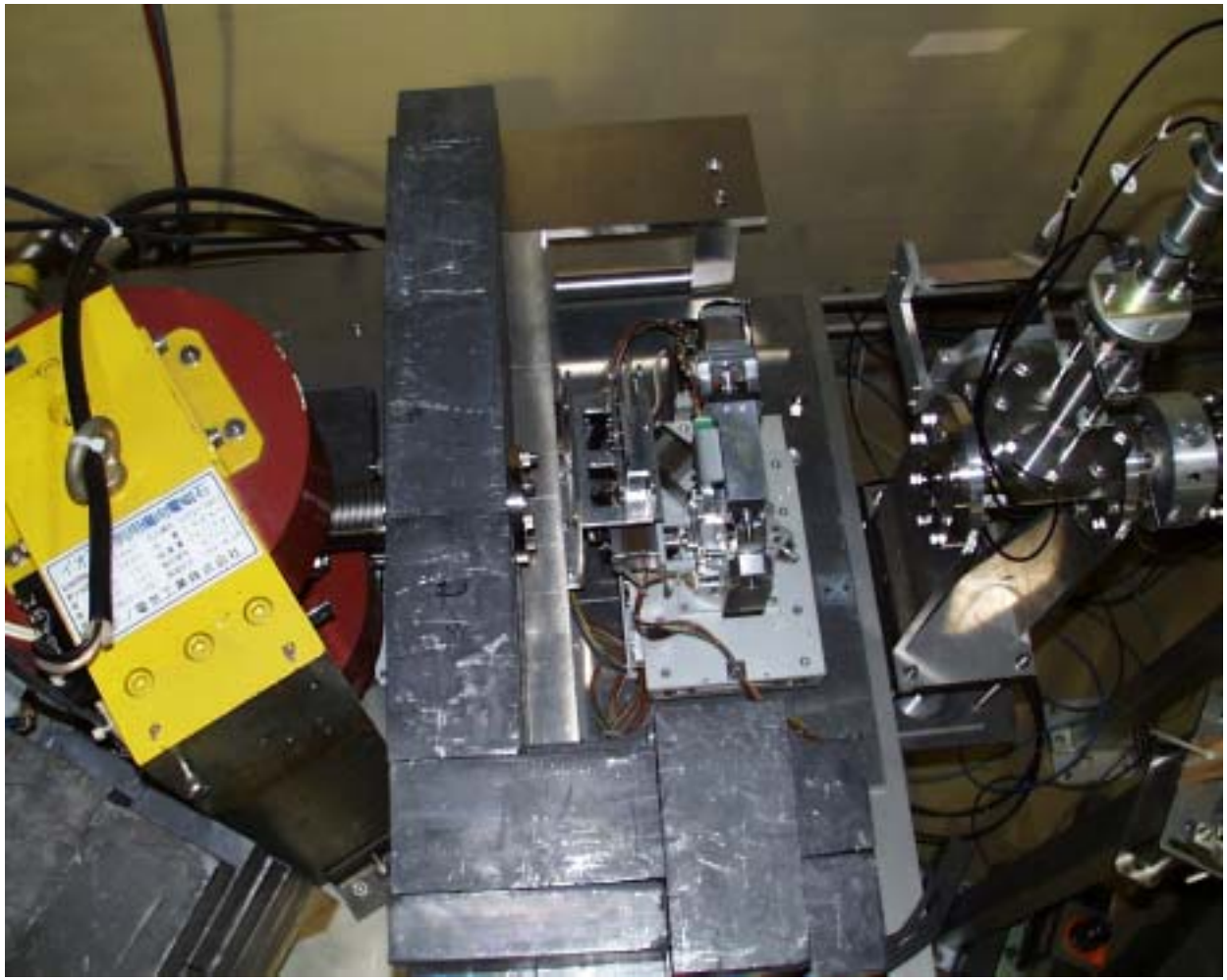
Linac Beam Line at the 3rd switch yard



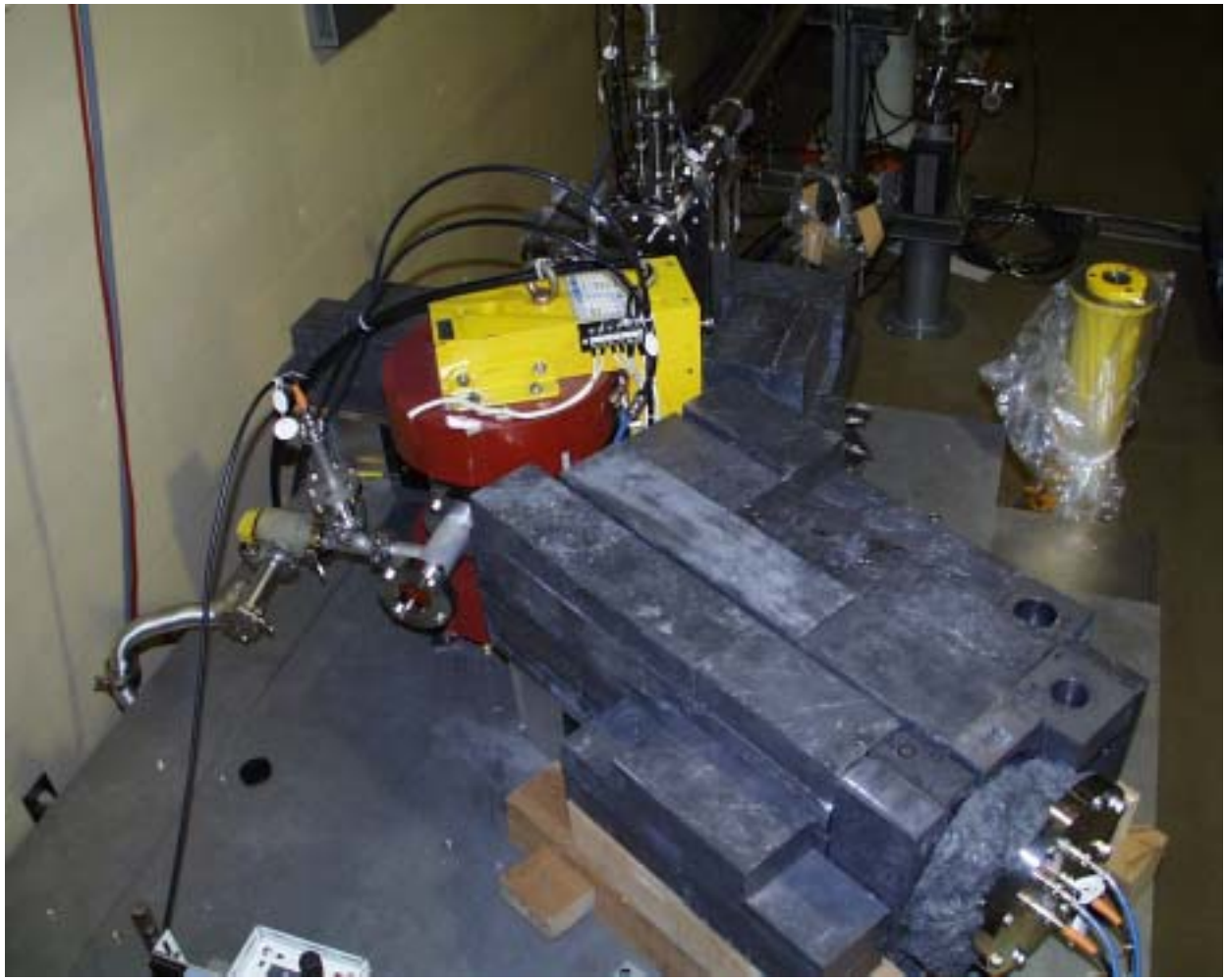
Experimental Setup (cont'd):Photo picture of a crystal target on a goniometer



Experimental Setup (cont'd):Photo picture of crystal & amorphous targets



Experimental Setup (cont'd):Positron spectrometer



Acceptance of the Positron Spectrometer

Pe+ (MeV/c)	Acceptance ($\Delta P \Delta \Omega$) (10^{-4} x (MeV/c)•sr)
5	1.08 ± 0.03
10	2.47 ± 0.07
15	3.80 ± 0.1
20	4.81 ± 0.12

- **The acceptance ($\Delta P \Delta \Omega$) was obtained by using the simulation code (GEANT3).**
- **Typical acceptance Momentum: $\Delta P/P$=2.4% (FWHM)& Geometrical: $\Delta \Omega$=1msr at Pe+=20MeV/c.**

Experimental Condition

***Electron Beam*:**

- **Beam Energy = 8 GeV**
- **Angular Spread ~22 μrad (H), ~44 μrad (V)**
- **Transverse Beam Size ~0.8mm (FWHM) in diameter**
- **Beam Charge = 0.1 nC/bunch**
- **Bunch Length (Single Bunch) ~9 ps (FWHM)**
- **Beam Repetition = 25Hz**

Angular Spread of the Electron Beam at the Positron Target

- **Φ ~ 55 μrad < Φc (due to multiple scattering by a beam-extraction vacuum window(30μm-thick SUS))**

Critical Angle for the Channeling Condition at the Positron Target

Linhard Crytical Angles

- **Φc ~ 170μrad @8 GeV for Silicon Crystal**
- **Φc ~ 130μrad @8 GeV for Diamond Crystal**

Experimental Condition (cont.)

***Positron-Production Targets*:**

- **Crystal Silicon Target : 2.55, 9.9, 29.9 and 48.15mm thickness**
- **Crystal Diamond Target : 4.57mm thickness**
- **Amorphous Tungsten Target: 3-18mm (3mm step) thickness (for the purpose of hybrid targets and for the e^+ production yield calibration)**

Detected Momentum Range:

- **10 MeV/c $\leq Pe^+ \leq$ 30 MeV/c**

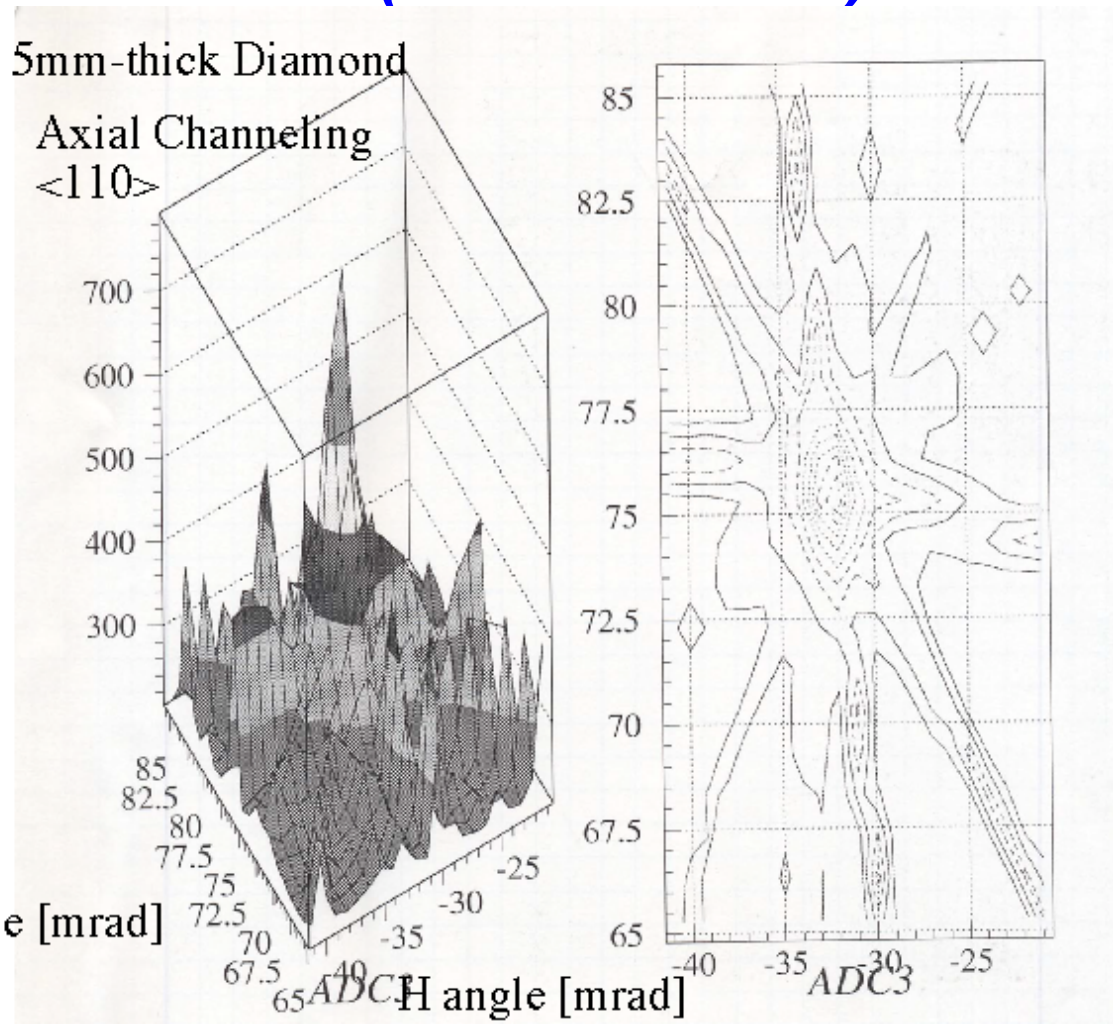
Positron Detectors

- ***Lead-Glass Calorimeter:Measurement of total energy of e+***
- ***Acrylic Cherenkov Counter:Measurement of number of e+***

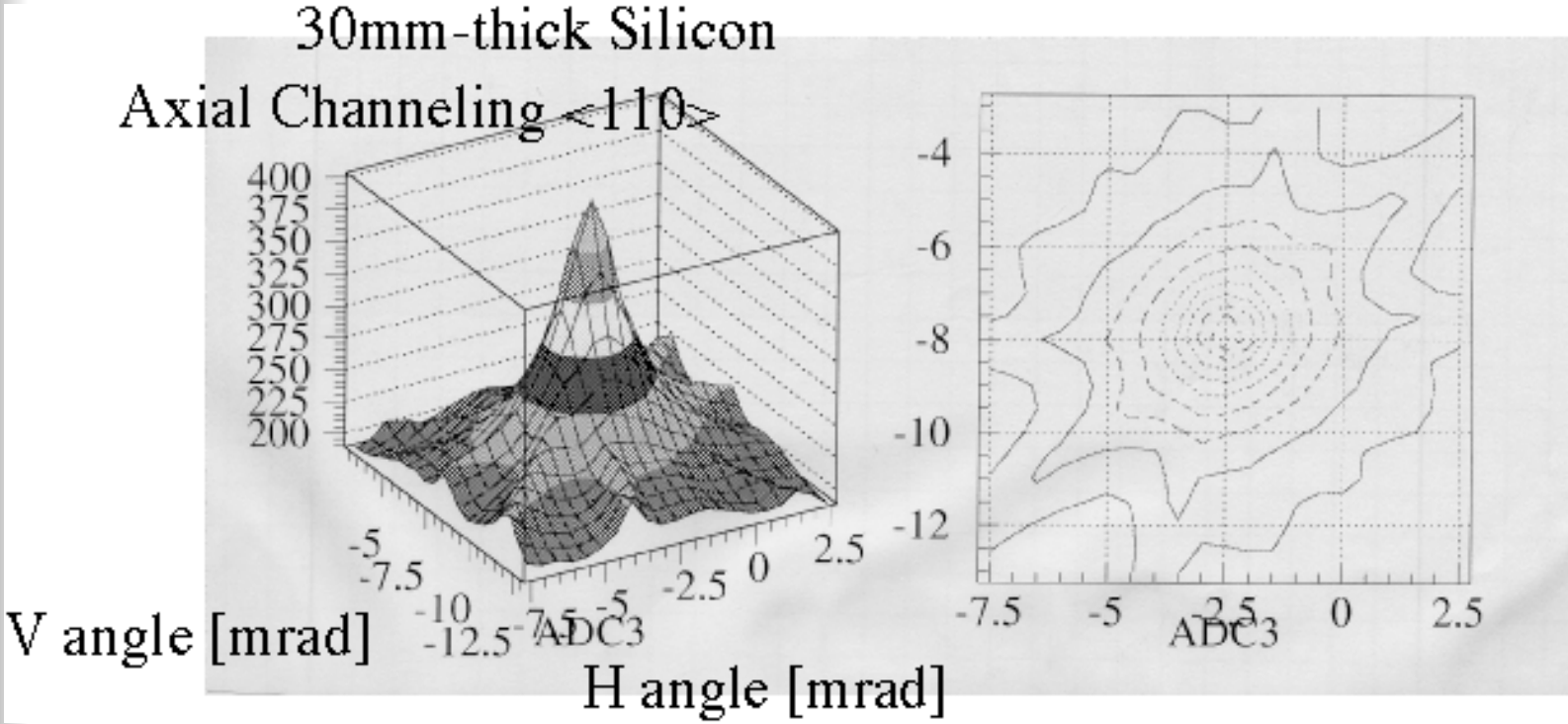
Beam Monitors

- ***Wall-current monitor* for the electron beam-charge measurement**
- ***Screen monitor* for the beam-profile measurement**

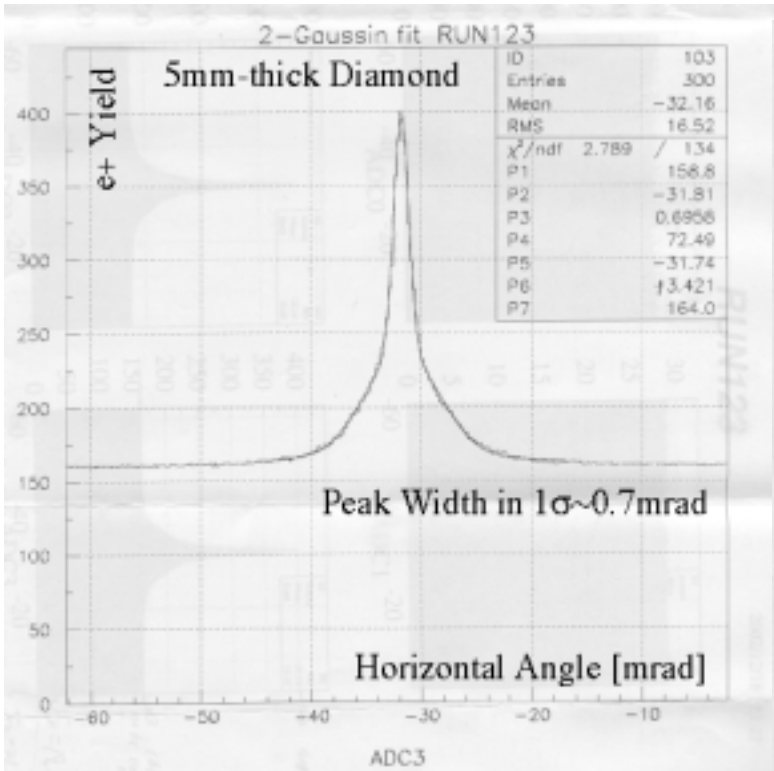
Experimental Results: 2-Dimensional Axis Scan for 5mm-thick Diamond Crystal at Ee-=8 GeV (Pe+=20MeV/c)

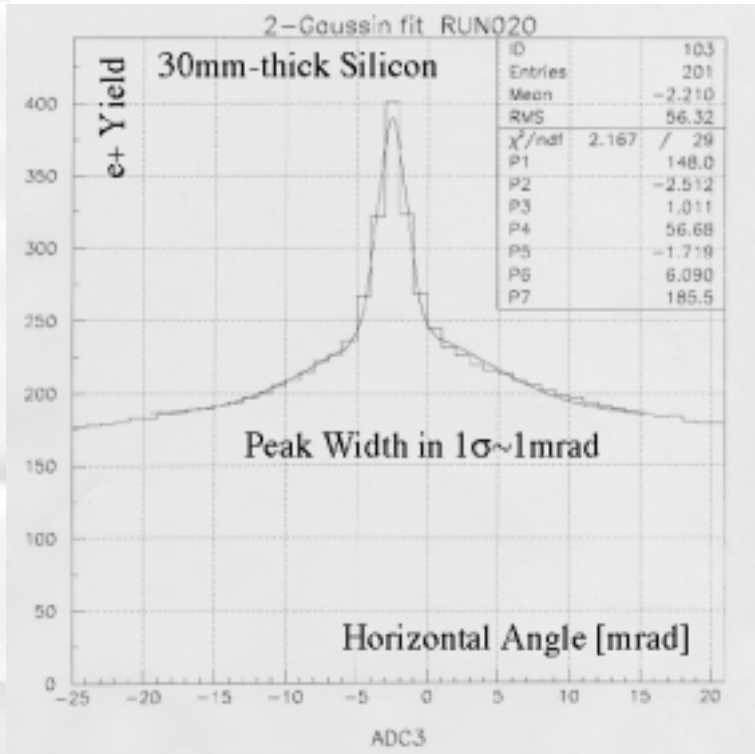


Experimental Results: 2-Dimensional Axis Scan for 30-mm thick Si Crystal at Ee-=8 GeV (Pe+=20MeV/c)

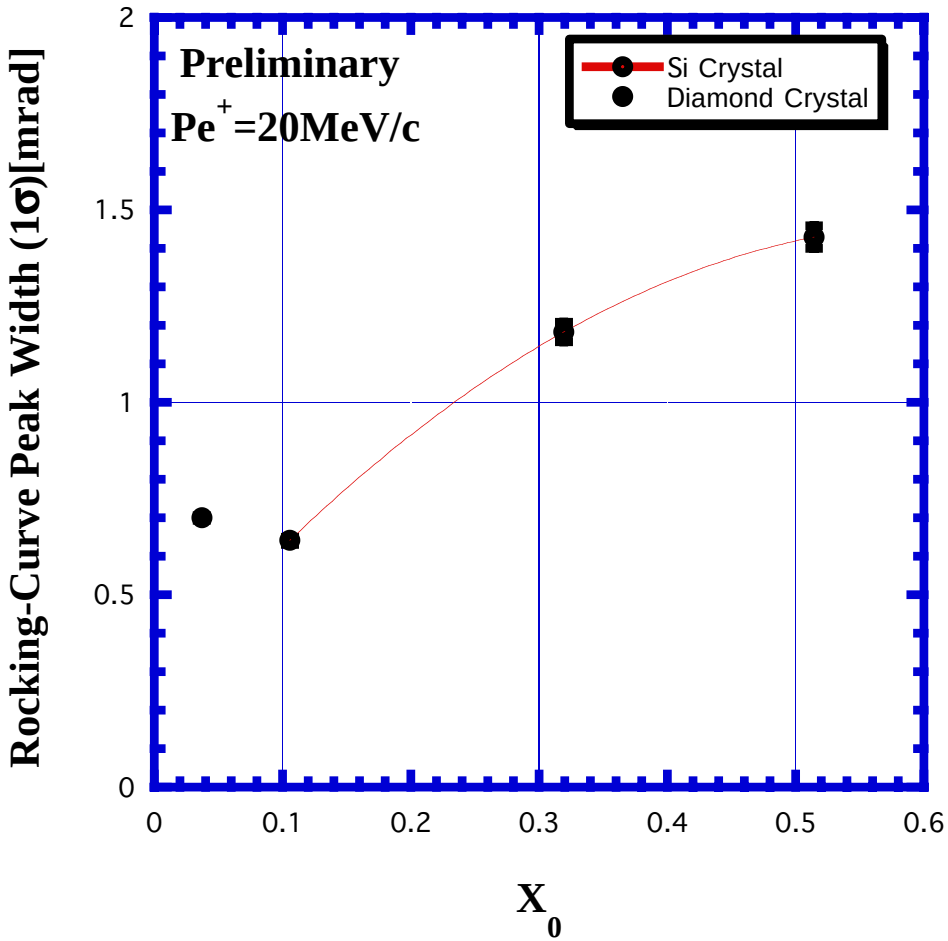


Experimental Results: Rocking Curves (Axis <110>) for 5mm-thick Diamond and 30mm-thick Si Crystals at Ee-=8 GeV (Pe+=20MeV/c)

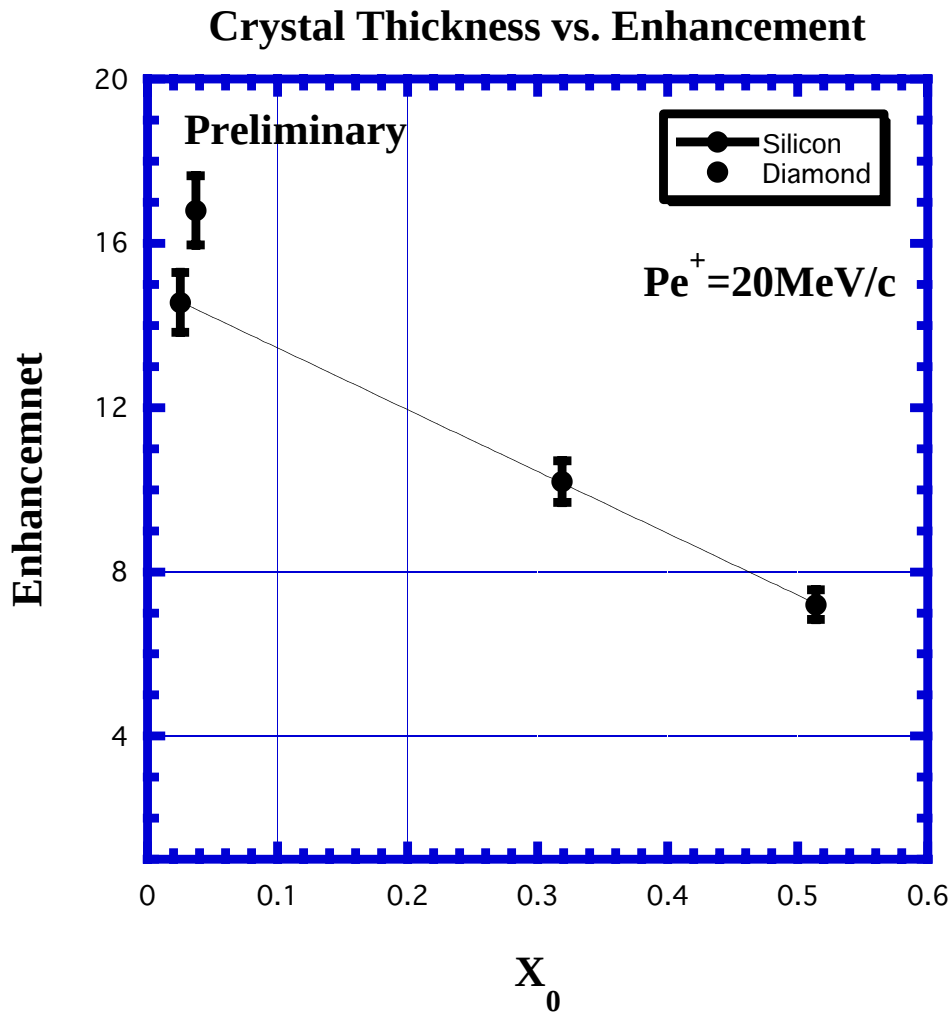




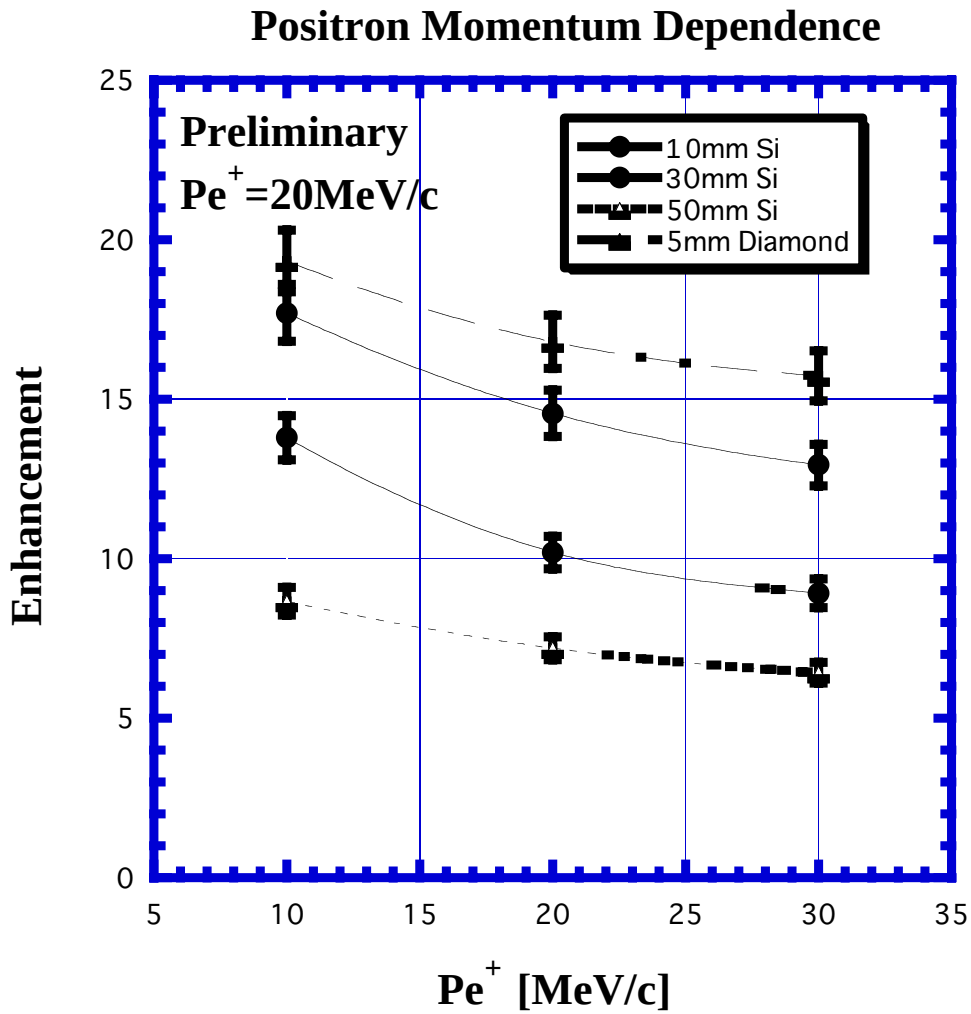
Experimental Results: Variations in the width of the rocking-curve peak for Ee-=8 GeV (Pe+=20MeV/c)



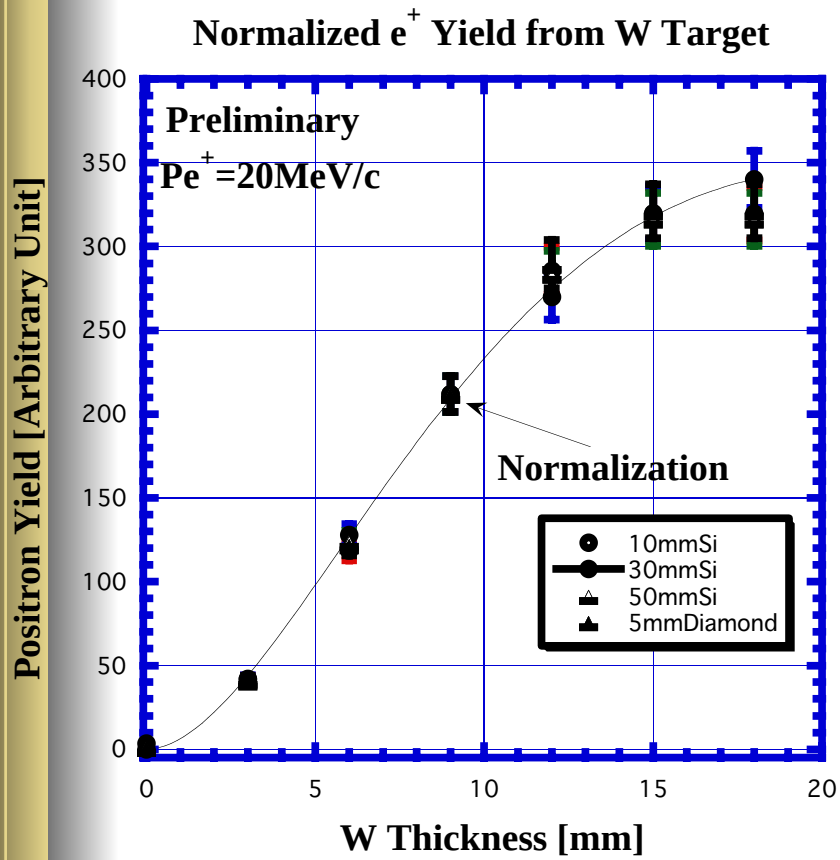
Experimental Results: Variations in the enhancement ($N_{e+@peak}$/ $N_{e+@base}$) of the e+ yield at Ee-=8 GeV (Pe+=20MeV/c)

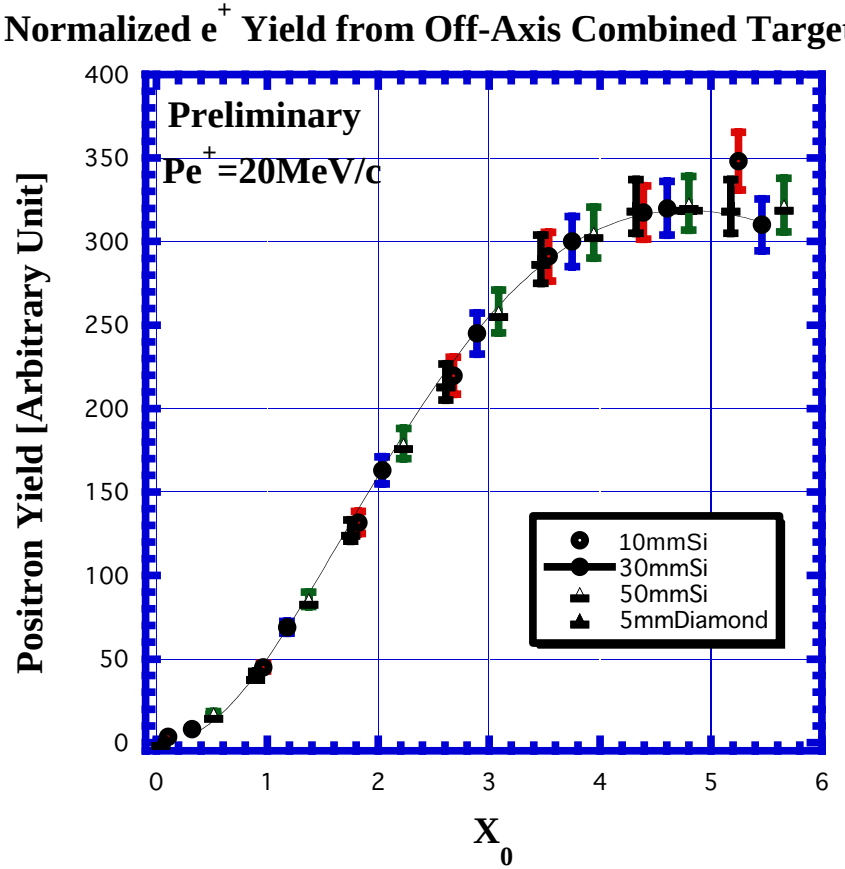


Experimental Results: Positron momentum dependence for the e+ yield enhancement at Ee-=8 GeV

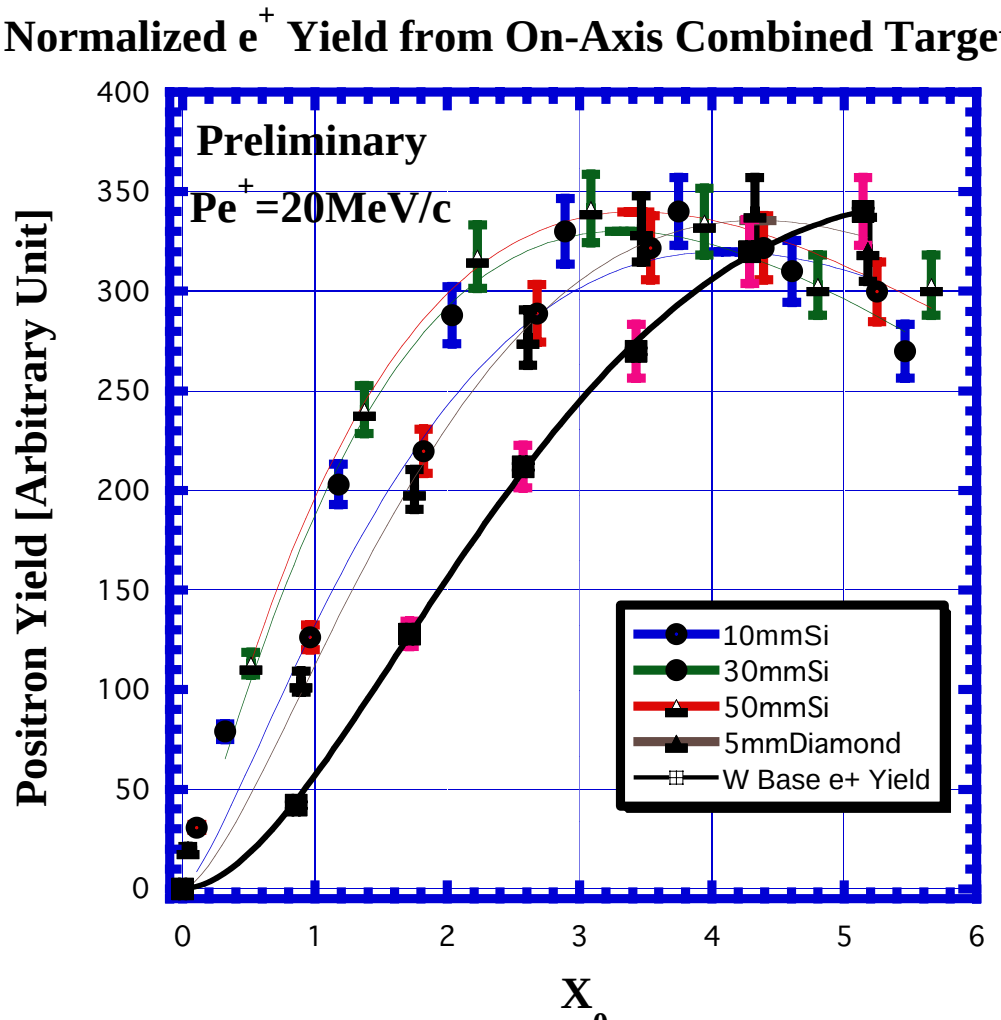


Experimental Results: Variations of the e+ production yield for the amorphous tungstens and off-axis crystal targets at Ee-=8 GeV (Pe+=20MeV/c)

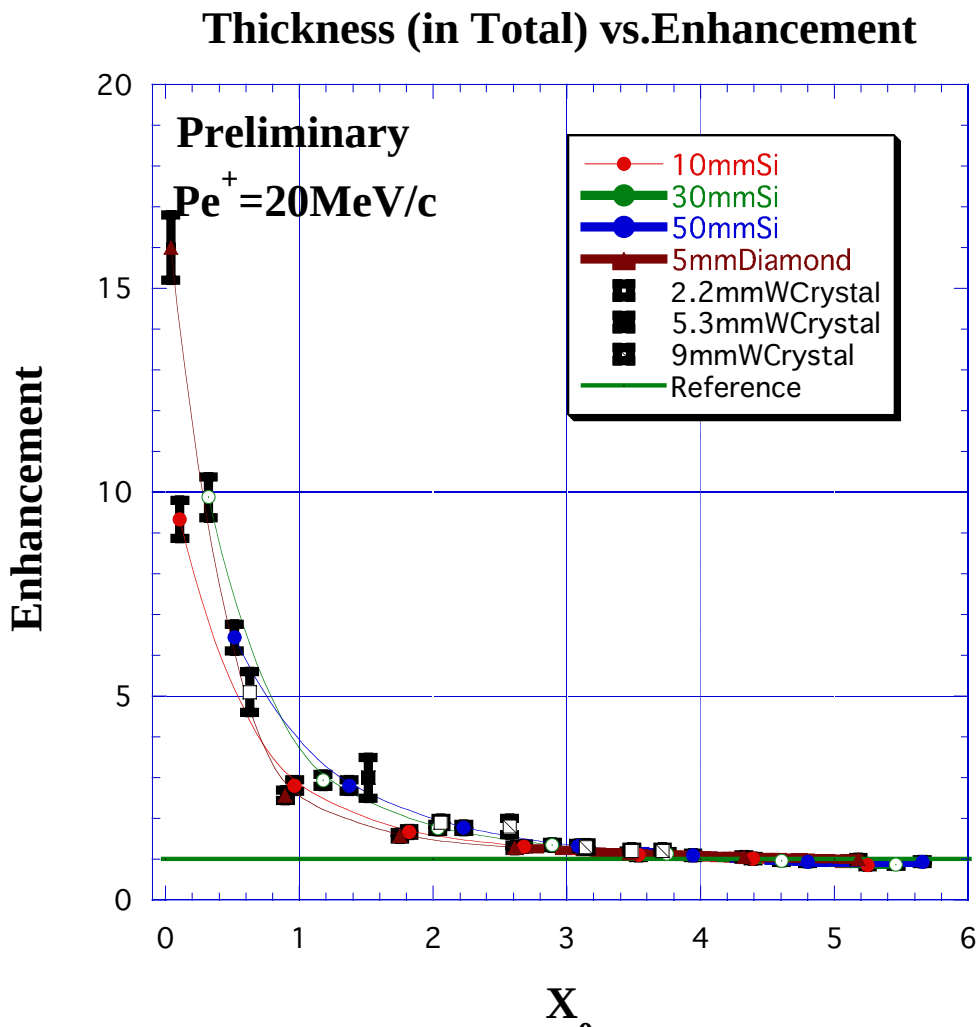




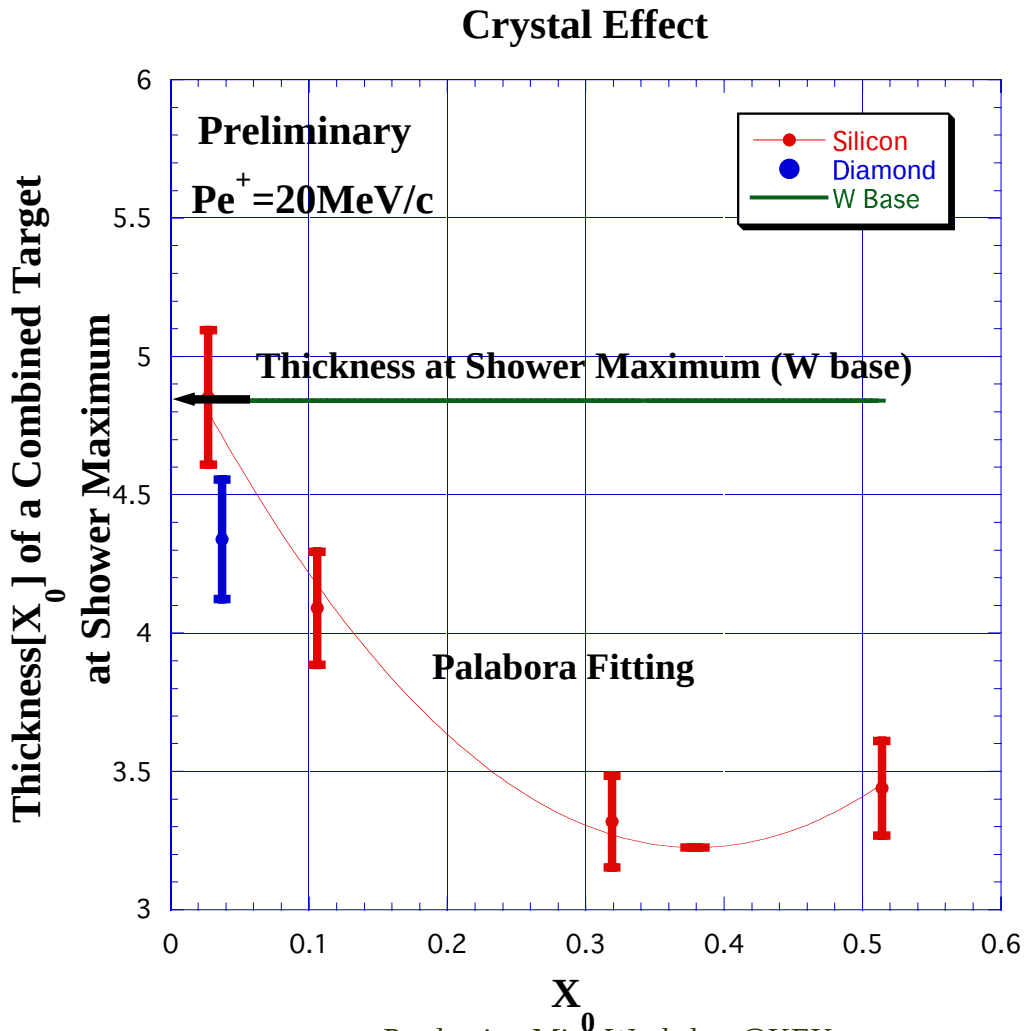
Experimental Results: variations of the e+ production yield for the on-axis crystal targets at Ee-=8 GeV (Pe+=20MeV/c)



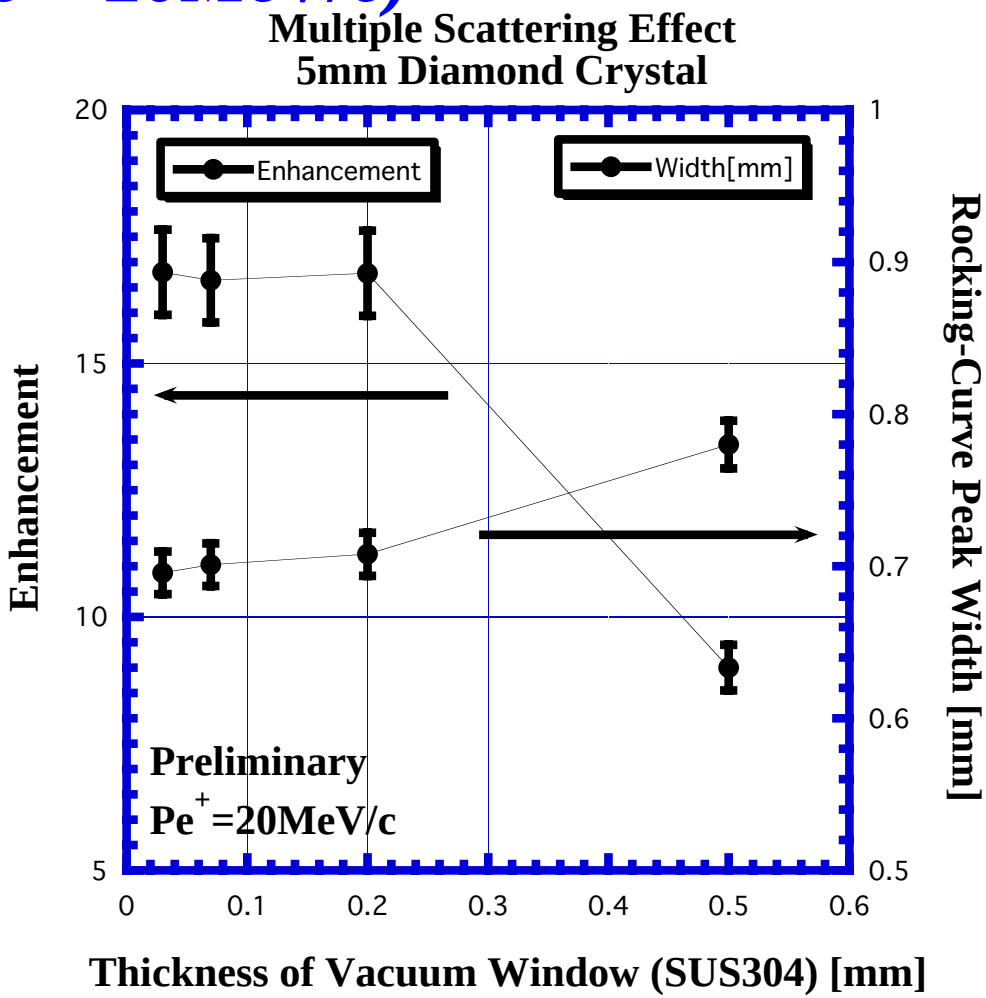
Experimental Results: Variations of the e+ production enhancement for the crystal targets at Ee-=8 GeV (Pe+=20MeV/c)



Experimental Results: Crystal effects for the Diamond and Si crystal targets at Ee-=8 GeV (Pe+=20MeV/c)



Experimental Results: Multiple Scattering Effect of the Vacuum Windows Using the Diamond crystal at Ee-=8 GeV (Pe+=20MeV/c)



Conclusions

- ***Positron production experiment using Diamond and Silicon crystal targets has been successfully performed at the KEKB 8-GeV electron linac.***
- *Rocking curves*

⇒ ***The obtained widths of the rocking-curve peak is larger than the critical angle,***

⇒ ***and broaden with the thickness of the crystal target.***

⇒ ***These broad width of the rocking curves indicate that coherent bremsstrahlung is the predominant process over the channeling radiation process in this energy region.***

⇒ ***The increase of the peak width depending on the target thickness may come from the multiple scattering of the incident electrons in the target.***

Conclusions (cont'd)

♠*Enhancement (En) and momentum dependence of the e^+ yield for the crystal target alone from 8-GeV channeling electrons at a e^+ momentum of 20MeV/c*

⇒ ***En*= 9.3 ±0.5 (9.9-mmSi), 9.9 ±0.5 (29.9-mmSi),**

⇒ ***En*= 6.4 ±0.3 (48.15-mmSi), 16 ±0.8 (4.57-mmDiamond)**

- *The enhancement is much reduced with an increase of the total target thickness.*
- *No crystal effect enhances the e+ yield at the target thickness larger than ~4.2 X_0 in total.*
- *The e+ yields with Pe+=20MeV/c at Ee-=8GeV were almost the same level as the maximum e+ yield obtained for the amorphous tungsten target.*

♠*New scheme using the combined crystal target indicates that heat load in the amorphous tungsten part of the target could be considerably reduced due to a small amount of the energy loss in total.*

⇒ *It is of great benefit to apply such a crystal target to a high-intensity e+ source required for high-luminosity e+e- colliders and B-fatories.*