USE OF CHANNELING RADIATION IN CRYSTALS FOR INTENSE POSITRON SOURCES

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USE OF CHANNELING RADIATION IN CRYSTALS FOR INTENSE POSITRON SOURCES

- **OUTLINE**
- **- Introduction**
- **- Main features of channeling radiation**
- **- First proposition & Proof of principle**
- **- Theoretical studies, simulations and experiments for an intense e+ source**
- **{All crystal, hybrid, hybrid-granular }**
- **- Applications for future colliders**
- **- Summary and conclusions**

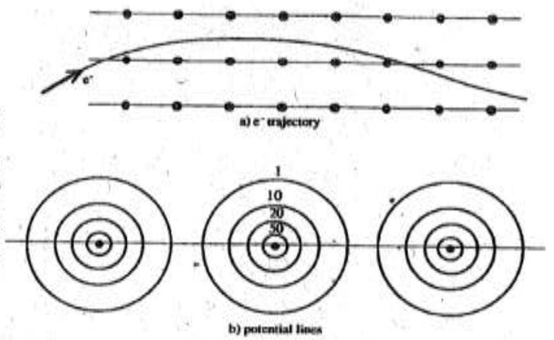
USE OF CHANNELING RADIATION IN CRYSTALS FOR INTENSE POSITRON SOURCES

- **INTRODUCTION**
- * Investigations on low emittance and intense positron sources motivated by future linear colliders
- * Channeling radiation in crystals is providing more radiation and photon numbers than bremsstrahlung under specific conditions. A first theoretical study using incident electron beams of 20 GeV and Silicon/Germanium crystals followed by an amorphous W converter showed significant enhancement in photon and positron production as well. A proof of principle test carried out at LAL-Orsay confirmed the expectations. A collaboration started with theoreticians from BINP (Baier-Katkov-Strakhovenko) in order to study, in association with IPNL physicists (X.Artru et al) the main features of this kind of source. An experiment on the transfer lines of the SPS-CERN was decided and prepared with an experimental group of BINP (S.Serednyakov et al). The experiment done in 2000-2001 provided useful data and a precise description of this kind of source in terms of phase-space. The collaboration with BINP extended beyond the CERN experiment with the continuous collaboration of Vladimir Strakhovenko. The promising results of these studies led to the choice of this kind of source as the baseline for CLIC collider. Further experiments have been operated at KEK-Tsukuba.
- The development of this e+ source was done in the framework of a continuous collaboration between French and Russian laboratories, mainly with BINP. This talk is dedicated to the memory of V.N.Baier and V.MStrakhovenko

USE OF CHANNELING RADIATION IN CRYSTALS FOR INTENSE POSITRON SOURCES

- RADIATIONS IN CRYSTALS
- * Bremsstrahlung (individual atoms)
- * Channeling and Coherent Bremsstrahlung

CHANNELING

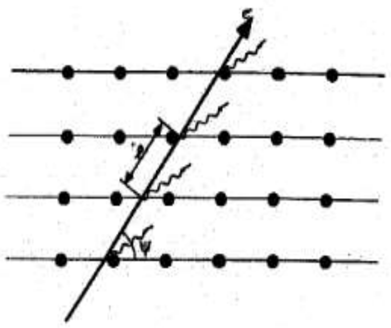


Fast particles undergo collective interaction with some subset of regularly spaced atoms. To a first approximation, a particle running nearly parallel to a major axis - which we take to be the *z-axis*-feels only a *continuous potential*[16] :

Figure 10 : Axial channeling on a Si < 111 > crystal.

$$\bar{V}(x,y) = << V(x,y,z,t) >_t >_z \quad (27)$$

COHERENT BREMSTRAHLUNG



Radiation associated with aligned crystals includes also *"coherent bremsstrahlung"* obtained at angles much larger than the critical angle. In that case, the particle crosses planes or chains of atoms and induced oscillations with interference effects appear.

Figure 11 : Coherent bremsstrahlung.

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1- MAIN FEATURES OF CHANNELING RADIATION

PECULIARITIES OF CHANNELING RADIATION W.R.T. BREMSSTRAHLUNG

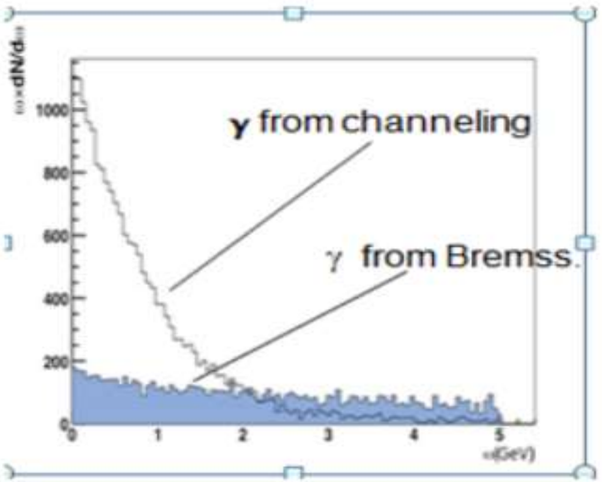
•Enhancement in photon radiation

•* There is a threshold in energy for which the energy radiated by channeling becomes more important than that of bremsstrahlung: it depends on crystal and incident energy: for W E_{thres} > 700 MeV. For other crystals (Si, Ge, C(d)) the threshold is higher.

•[See V.N.Baier, V.M.Katkov, V.M.Strakhovenko in Phys.Stat.Solidi 133 (1986)583-592]

•* Softer photons

•* With channeling the photons are softer and, consecutively, the e- e+ pairs generated by them.



Crystal and amorphous targets of same thickness

The vertical scale is in ω.dN/dω; as the bremsstrahlung has a law in 1/ω it is easier to see the difference.

Simulations with E-=5 GeV; W crystal [<111> axis; 1.4 mm thick]]

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- **OPTIMIZATION OF THE RADIATION CHARACTERISTICS**
- # Choice of crystals with good mosaicity: test with γ sources
- # Choice of axis vs plan ➔ stronger potentials
- # Choice of high Z materials (for W, Potential well depth Uo ~ 1kV at room temperature)
- # Incident electron beam with weak divergence $\theta < \psi_{cr}$ | $\psi_{cr} = \sqrt{(2Uo/E)}$
- # Moderate crystal thickness: there is an optimum thickness (Lo) for which the radiation is maximum at a given collimation angle (V.N.Baier et al.). For GeV e- energies:
- $\max(\gamma^{-1}, \psi_{cr}) < \theta_{coll} < < \theta_s$
- Calculations (BKS) give an optimum length of 0.65 mm for W <111> at normal temperature and at 1 GeV . For this value, the optimum collimation is ~ some mrad (θ_s ~ 6.5 mrad)
- In our simulations for ILC and CLIC projects we have chosen Lo=1 mm for E-=10 GeV and Lo = 1.4 mm for E-= 5 Gev.

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2-CHANNELING RADIATION AND POSITRONS

At the end of the eighties, a group from Orsay proposed to replace the magnetic undulator* by a crystal to create an intense beam of photons; the proposition was presented at PAC 1989

An hybrid source using an atomic undulator (Proc. of PAC, Chicago, 1989)

R. Chehab, A. Artru, F. Couchot, A.R. Nyaiesh, F. Richard

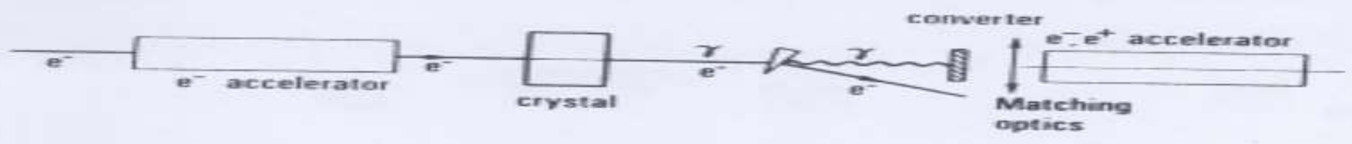

Figure 6 : Layout of a positron source using channeling

Simulations of an hybrid source made of Ge or Si crystals as radiators and amorphous W as converters:
For Ge and Si crystals oriented on <110> axis and 1 cm thick, we had e+ accepted yields of 0.5 to 0.6 e+/e- for 0.5 Xo thick converter and 1.2 to 1.3 e+/e- for 1 Xo thick; the incident e- energy is 20 GeV

*** Use of a magnetic undulator for production of polarized photons was proposed for VLEPP (Balakin, Mikhailichenko, 1979)**

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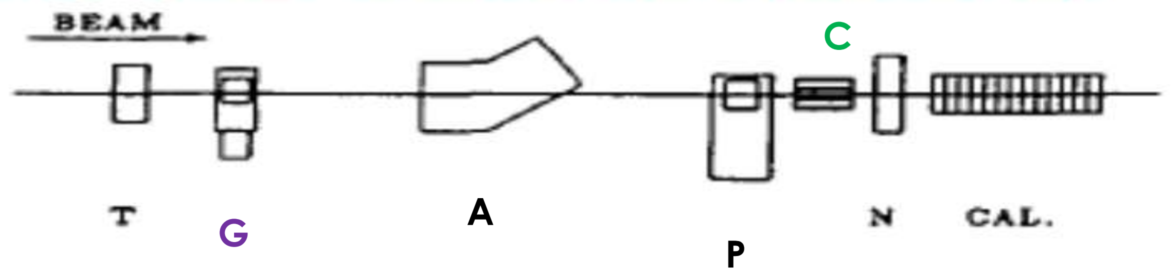
- PROOF OF PRINCIPLE AT ORSAY (Photons only)



T: induction monitor
G: goniometer+crystal
A: bending magnet
P: profile monitor (SEM grid)
C: collimator
N: scintillator
CAL: calorimeter

Fig. 10. Lay-out of the channeling experiment at Orsay.

The idea supported by V.N. Baier led to a simplified scheme where only the photons were measured. Such experiment was done in 1992-93 by French physicists with participation of a BINP colleague (T. Baier)

USE OF CHANNELING RADIATION IN CRYSTALS FOR INTENSE POSITRON SOURCES

- **PROOF OF PRINCIPLE**

□ **THE RESULTS OF ORSAY EXPERIMENT**

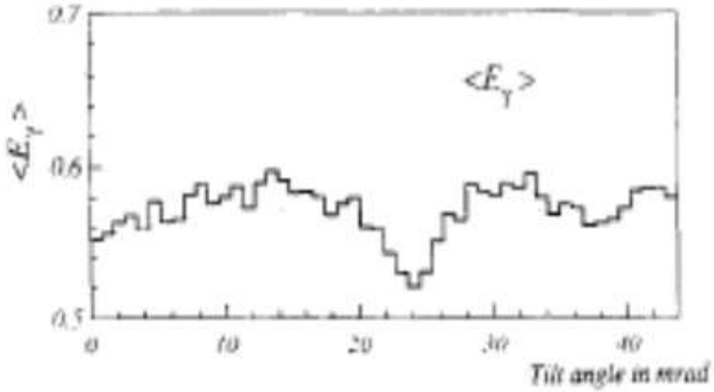


Fig. 12. Average photon energy, in arbitrary units, versus tilt angle between ⟨111⟩ axis and electron beam for an incident energy of 2 GeV. Rotation axis is the vertical one, the collimation angle is 1 mrad (from Ref. [14]).

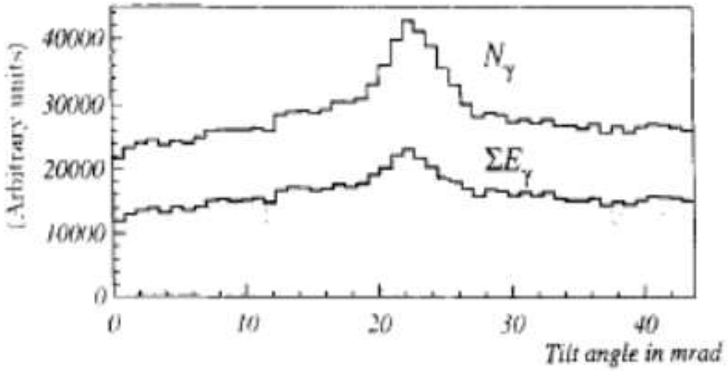
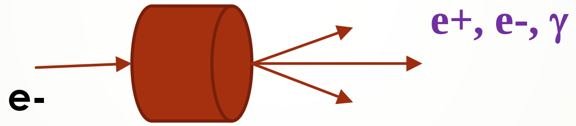


Fig. 11. Photon yield and radiated energy from a 1 mm thick tungsten crystal versus tilt angle between ⟨111⟩ axis and electron beam for an incident energy of 2 GeV. Rotation axis is the vertical one, the collimation angle is 1 mrad (from Ref. [14]). Both curves are represented in arbitrary units for the vertical scale.

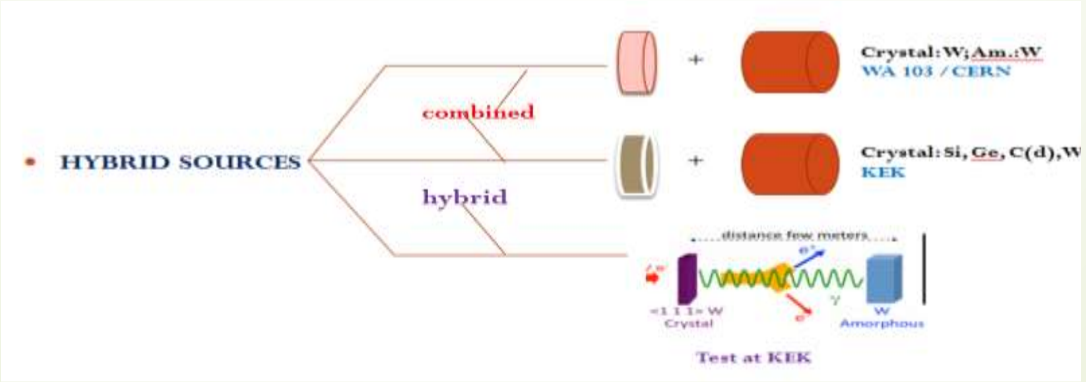
On the W crystal <111> axis, we observed an enhancement in the production of soft photons with respect to the random regime (amorphous)

USE OF CHANNELING RADIATION IN CRYSTALS FOR INTENSE POSITRON SOURCES

- **STUDIES FOR AN INTENSE POSITRON SOURCE USING CHANNELING**
- **Photons created in oriented crystals (Channeling, Coherent Bremsstrahlung, Bremsstrahlung) and materialization of these photons in e+e- pairs could be carried out in the same target or in two separated targets [radiator and converter]:**
- *** Thick crystal**



- *** Hybrid**



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- THE ALL-CRYSTAL SOURCE
- THE WA 103 EXPERIMENT (CERN)

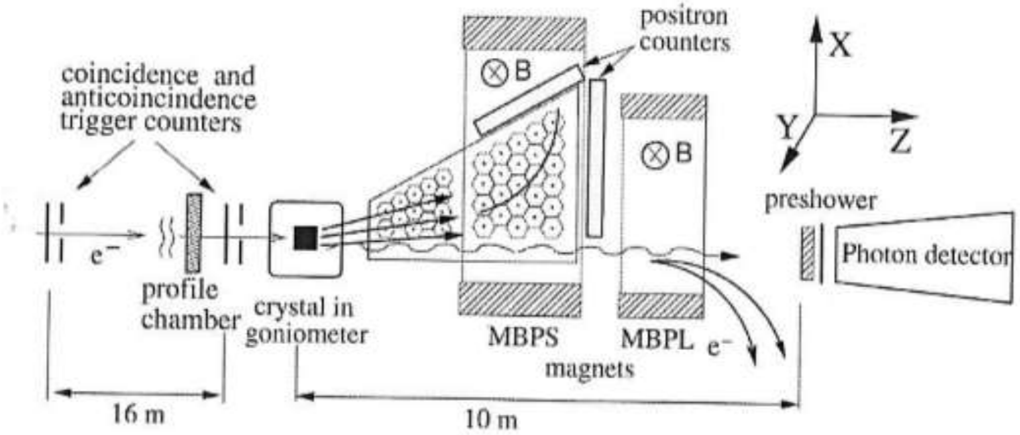

Fig. 1. The setup scheme. Drift chamber in two parts. DC1 is outside the magnetic field. DC2 is in the magnetic field of MBPS magnet. MBPL is the sweeping magnet.

Involvements of young physicists from BINP and TPU (S.Burdin, V.Shary, T.V.Baier, K.Beloborodov, A.Bogdanov) have been essential.

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CRYSTAL POSITRON CONVERTERS: a single crystal plays the role of radiator and converter.

* Experiment at CERN: WA 103; a single crystal (4 or 8 mm thick) , oriented on its <111> axis and submitted to high electron energies from 5 to 40 GeV. The yield is depending from the incident energy and on the crystal thickness. We are showing the positron yield obtained with a 8 mm W crystal and an incident energy of 10, 20 and 40 GeV (measurement on side e+ counters)

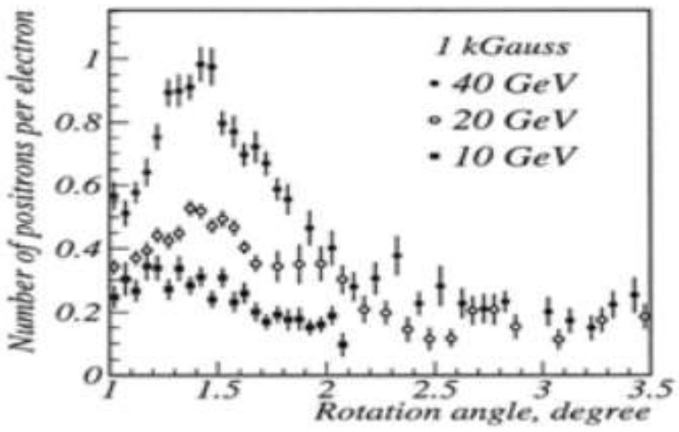

Figure 115: Rocking curves.

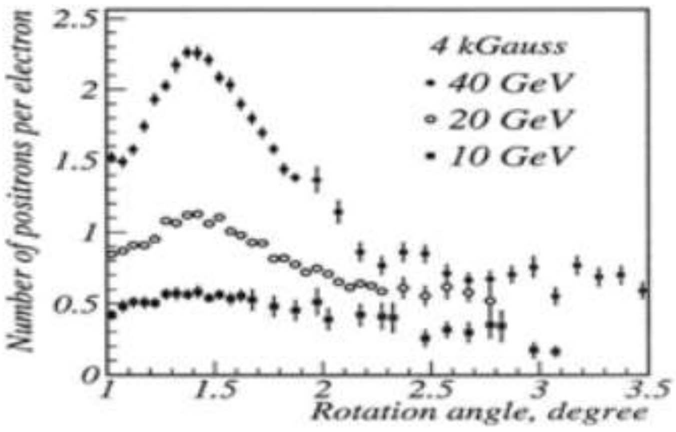

Figure 116: Rocking curves.

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SOME RESULTS OF THE CERN EXPERIMENT WA 103

Enhancements in photon and positron production were measured for 4 and 8 mm crystals oriented on <111> axis. Comparisons with random orientation showed an enhancement of 4 for the 4 mm crystal w.r.t. amorphous of the same thickness (figure below) , whereas it was of 2 for 8 mm crystal.

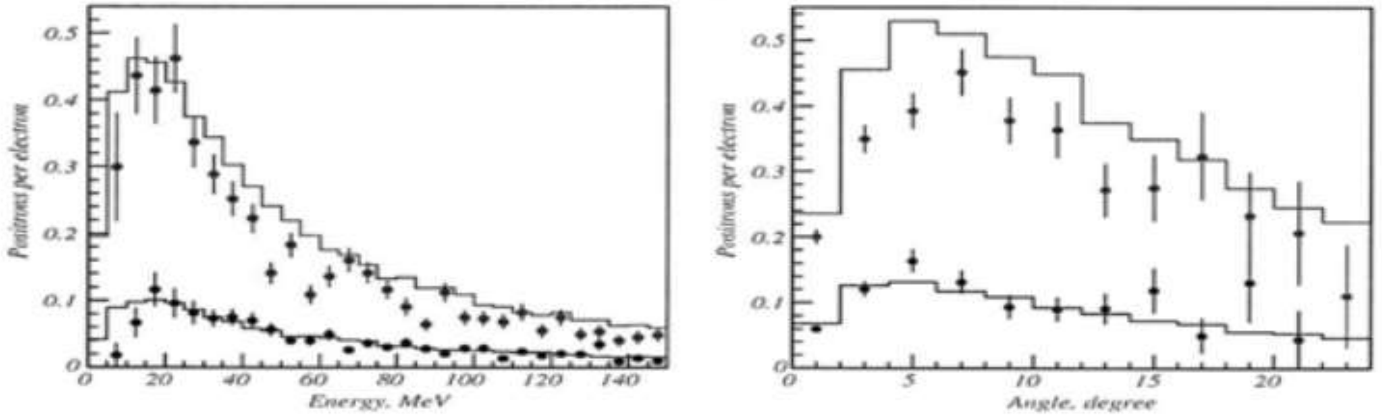

Fig. 11. The positrons horizontal momentum p_h (left) and angular (right) distributions for one incident electron and 4 mm thick target. The electron energy is 10 GeV. The points with error bars are the experimental data. The histograms are the simulated spectra. The upper histograms and points on the plots correspond to the aligned crystal, the bottom histograms and points to the random crystal orientation. These distributions are corrected by the reconstruction efficiency and the detector acceptance.

Ref: R.Chehab et al. Phys.Letters B 525 (2002)41-48 and X.Artru et al. NIMB 240 (2005)762-776

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EXPERIMENT WA 103 (CERN)

It is interesting to represent the collected positrons in a diagram (p_L, p_T); as the capture magnetic system is defined by (max[p_L] and max[p_T] it is easy to derive the number of collected positrons. Data has been gathered for 4mm and 8 mm crystals.

12 Xtal 4 mm, 10 GeV

12.1 Two dimensional map

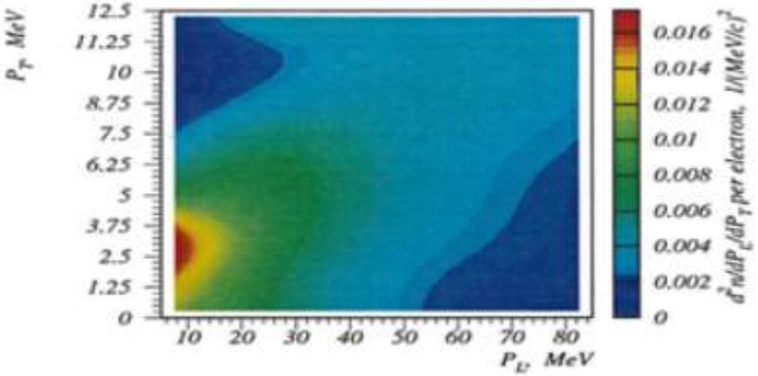

Figure 119: Experimantal map

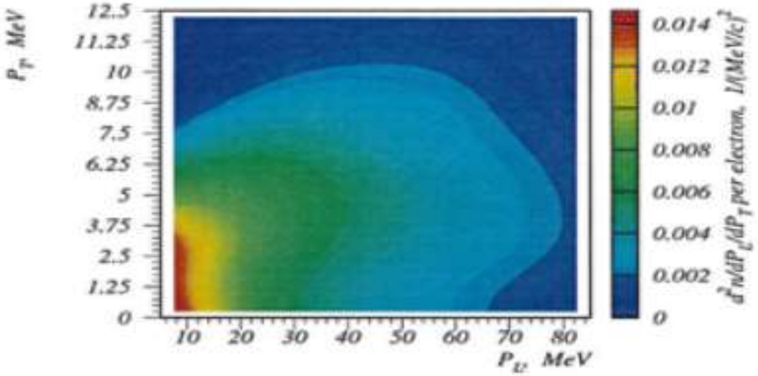

Figure 120: Calculated map

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WA103: POSITRONS ACCEPTED IN GIVEN PHASE SPACE [E-=10 GeV; l(cryst)=8mm)

Table 1
Positron yield: 8 mm crystal/10 GeV incident energy

	$5 < p_L < 25$ MeV/c	$5 < p_L < 30$ MeV/c	$5 < p_L < 40$ MeV/c
Experiment			
$p_T < 4$ MeV/c	1.16 ± 0.04	1.28 ± 0.04	1.43 ± 0.04
$p_T < 6$ MeV/c	1.66 ± 0.05	1.85 ± 0.05	2.13 ± 0.05
$p_T < 8$ MeV/c	2.11 ± 0.07	2.46 ± 0.08	2.90 ± 0.08
$p_T < 10$ MeV/c	2.31 ± 0.08	2.75 ± 0.08	3.32 ± 0.08
$p_T < 12$ MeV/c	2.40 ± 0.08	2.94 ± 0.09	3.67 ± 0.10
Simulation			
$p_T < 4$ MeV/c	1.34	1.49	1.69
$p_T < 6$ MeV/c	2.06	2.32	2.72
$p_T < 8$ MeV/c	2.56	2.94	3.51
$p_T < 10$ MeV/c	2.83	3.30	4.03
$p_T < 12$ MeV/c	2.93	3.49	4.35

Domains defined in longitudinal p_L and transverse p_T momenta.

It can be seen that such crystal converter satisfies the requisites for a linear collider (1e+/e- at IP)

USE OF CHANNELING RADIATION IN CRYSTALS FOR INTENSE POSITRON SOURCES

- CRYSTAL CONVERTER vs HYBRID SOURCE
- Some experiments have been carried out at CERN and KEK with different configurations:
- * Thick crystal (radiator + converter)
- Exp. CERN (WA103)

8 mm crystal — 4 mm crystal — 4 mm amorph.

Both kinds of targets have been tested at CERN. The positron yield was the same for the 8 mm crystal as for the (4 crystal +4 amorphous) .

X.Artru et al. NIMB 240 (2005)762

➔ It is not needed to have thick crystals

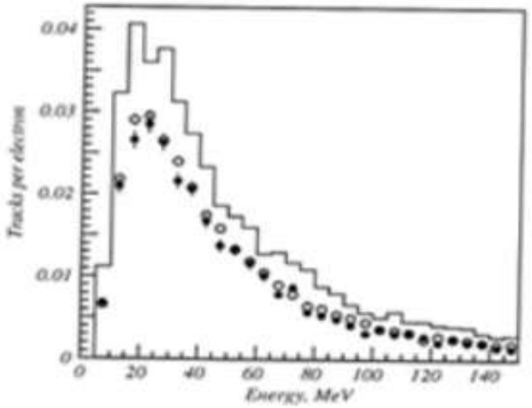


Fig. 12. The positrons energy spectra for the 1 kG magnetic field normalised per 1 incident electron. The spectra are not corrected by the reconstruction efficiency and the detector acceptance. The dark points represent the 8 mm crystal target. The open points, the "4 mm crystal target + 4 mm amorphous target". The histogram is the 8 mm crystal simulation. The electron energy is 10 GeV.

USE OF CHANNELING RADIATION IN CRYSTALS FOR INTENSE POSITRON SOURCES

- **THICK VS THIN CRYSTALS IN AN HYBRID POSITRON SOURCE**
- **The choice is determined by the photon yield, the energy deposited and the PEDD:**
- **Simulations for a W crystal submitted to 5 and 10 GeV e- ➔ thin crystals are preferable**

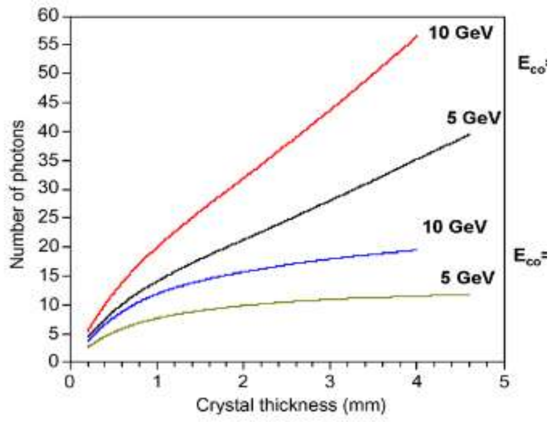


Fig. 2. Total photon yield versus crystal thickness for incid... energies of 5 GeV and 10 GeV, $E_{cut\ off} = 5$ MeV: upper curve... 50 MeV: lower curves.

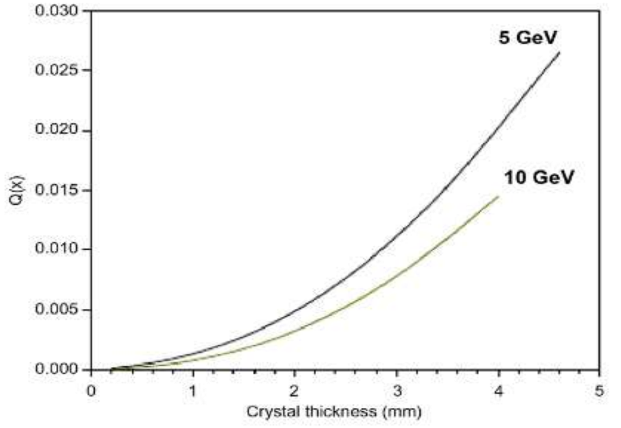


Fig. 3. Total energy deposited in the radiator: ratio $Q(x) = E_{dep}/E$ for $E = 5$ and 10 GeV.

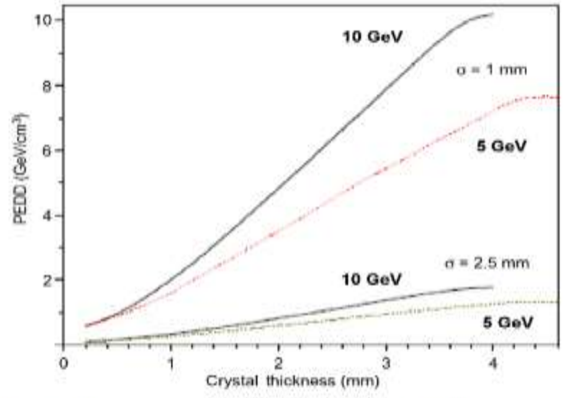


Fig. 4. PEDD versus crystal thickness for $E = 5$ and 10 GeV. For the upper curves, the r.m.s. incident beam radius is 1 mm and for the bottom curves, 2.5 mm.

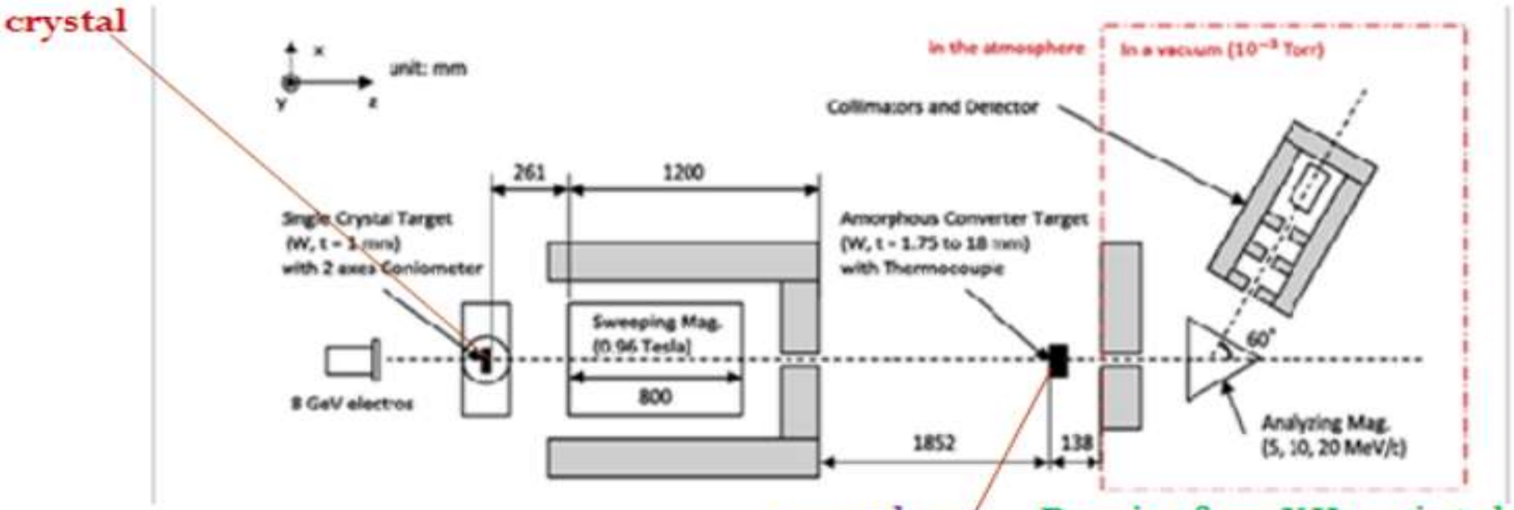
X.Artru, R.Chehab, M.Chevallier, V.M.Strakhovenko, A.Variola, A.Vivoli, NIMB 266 (2008) 3868-3875

USE OF CHANNELING RADIATION IN CRYSTALS FOR INTENSE POSITRON SOURCES

- HYBRID SOURCES
- WHY USING AN HYBRID SOURCE:
- * Use of a thin crystal leads to less energy deposition in the crystal → less heating → preservation of the high available potential well depth→ more efficient channeling. Less deposited power on the converter (sweeping magnet)
- In the converter the density of the energy deposition is getting lower because of the elimination, by the sweeping magnet, of the charged particles coming out from the crystal and also due to the distance 2-3 meters between the two targets. This is important to lower the PEDD [Peak Energy Deposition Density] which is harmful {cf. SLC target}

USE OF CHANNELING RADIATION IN CRYSTALS FOR INTENSE POSITRON SOURCES

- POSITRON SOURCE EXPERIMENTS AT KEK
- Two kinds of positron source tests have been operated at KEK:
- * Experiments with an hybrid source
- * Experiment with a crystal-radiator-converter
- 1- EXPERIMENTS WITH AN HYBRID SOURCE

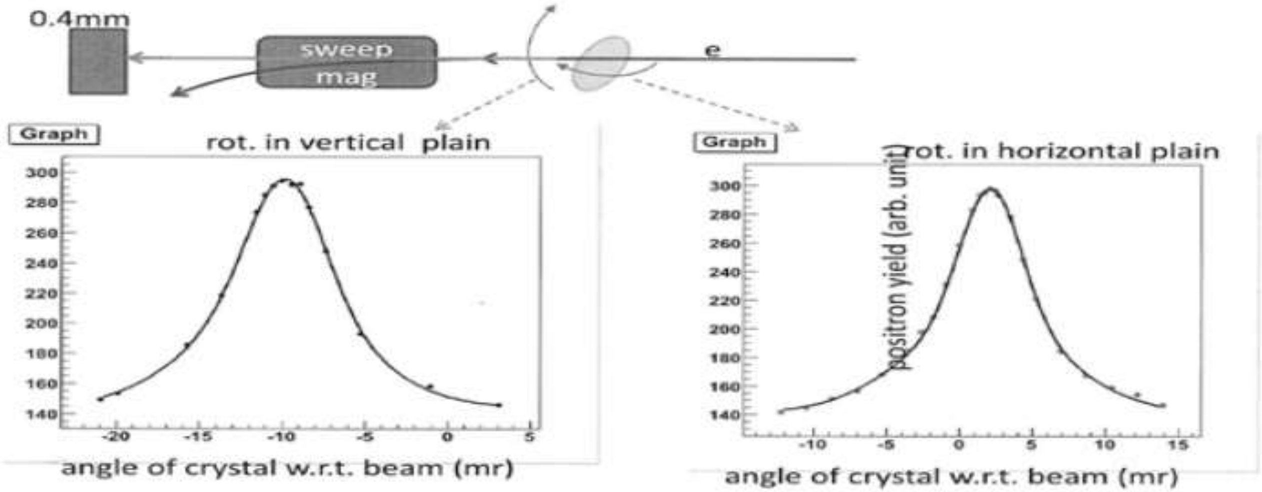


Drawing from Y.Uesugi et al.NIMB

USE OF CHANNELING RADIATION IN CRYSTALS FOR INTENSE POSITRON SOURCES

TEST OF AN HYBRID POSITRON SOURCE AT KEK (2009)

The W crystal is 1 mm thick and the amorphous W is 0.4 mm thick. Impinging electron energy on the crystal is 8 GeV. The sweeping magnet being on, only γ are incident on the converter. The enhancement due to channeling is clear.



Communication from T.Takahashi

Ref: Communication from T.Takahashi
(Hiroshima University)

USE OF CHANNELING RADIATION IN CRYSTALS FOR INTENSE POSITRON SOURCES

TEST AT KEK OF AN HYBRID SOURCE WITH A GRANULAR CONVERTER

Following an idea of P.Sievers for the target of a neutrino factory (protons on target ➔ $\pi+\pi-$ ➔ $\mu+\mu-$ ➔ ν), we considered a granular target made of small W spheres (2 mm diameter) instead of the compact W target. Four granular targets were built at LAL (2, 4. 6 and 8 staggered layers) and sent to KEK. Simulations have shown the ability of such targets to serve as converters providing equivalent yields and better performances for the deposited powers and Peak Energy Deposition Density (PEDD). For example the yield for a 8 mm compact converter is close to that of a 8 layers ghranular.

With respect to bulk targets a granular target made of small spheres (ϕ~ 1 mm) presents better heat dissipation

USE OF CHANNELING RADIATION IN CRYSTALS FOR INTENSE POSITRON SOURCES

THE GRANULAR TARGETS: CONVERTERS USED AT KEK

4 granular targets of 2, 4, 6 and 8 layers have been realized at LAL-Orsay and sent to KEK for the tests. The W sphere radius is 1.1 mm. The incident photons from the crystal are impinging on a layer made of 10x10 spheres. In the staggered disposition of the layers and using always an even number of layers, the exit face of the converter has 9x9 spheres with a central sphere on the axis. That allows to put a certain number of thermocouples on the exit face and especially on the centre of the exit face which corresponds in principle to the warmest position of the target. That helps for the PEDD determination.

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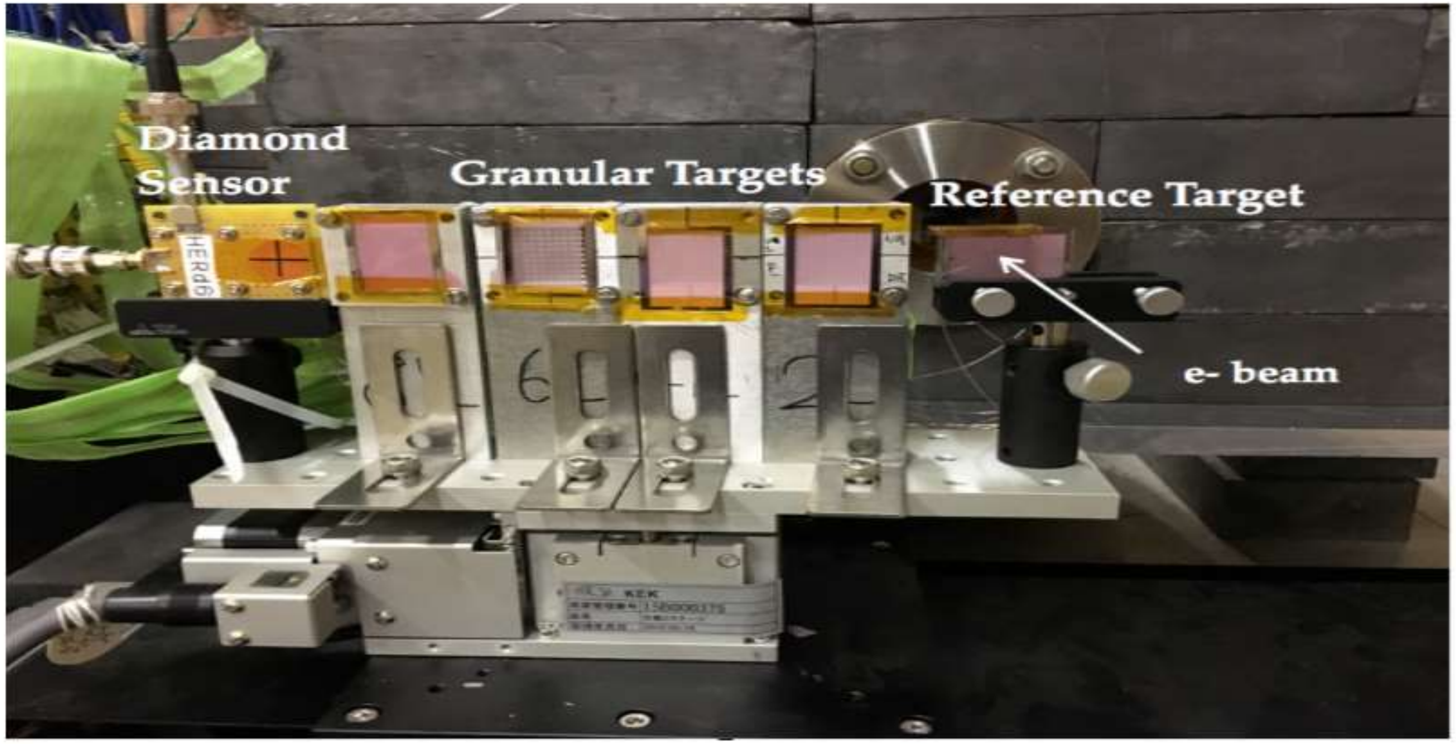
USE OF CHANNELING RADIATION IN CRYSTALS FOR INTENSE POSITRON SOURCES

TEST AT KEK OF HYBRID SOURCE (GRANULAR CONVERTER): october 2016

Translation stage: Granular targets + Reference target (8 mm compact) + photon detector (Diamond)



USE OF CHANNELING RADIATION IN CRYSTALS FOR INTENSE POSITRON SOURCES

- TEST OF THE HYBRID/GRANULAR SOURCE AT KEK: EXPERIMENTAL CONDITIONS
- * EXPERIMENTAL CONDITIONS:
- E-=7 GeV; single bunch (f=1 to 50 Hz); q(bunch) = 1-2 nC;
- Emittance (norm)~ 150(H)/63(V) π mm mrad; beam divergence< 0.1 mrad
- Crystal W: 1mm thick, <111> orientation
- Granular targets: 4, 6 and 8 layers; Compact target: 8 mm thick
- All amorphous targets on a translation stage; also for the γ detector
- Temperature rise on the converter :→ thermocouples

I.Chaikovska et al. article in preparation

USE OF CHANNELING RADIATION IN CRYSTALS FOR INTENSE POSITRON BEAMS

- DETECTION OF PHOTONS AND POSITRONS:
- * PHOTON DETECTION
- # crystal alignment using photon detector: CVD diamond detector 500 μm thick; electric field 400 V on electrode of diamond for charge collection; other electrode connected to Lecroy scope. Weak interaction efficiency (<1 %) but enough γ rays (>10^{11}). The diamond detector has 4x4 cm^2 dimensions.
- * POSITRON DETECTION
- # after the bending analyzer, Cherenkov Detector (Lucite, 5 mm thick)
- ➔ four values of E+ were chosen: 5, 10, 15 and 20 MeV.
- * TEMPERATURE MEASUREMENT
- # Thermocouples with area <1 mm^2 ; glued on W spheres of the exit layer (with epoxy thermal conductive paste). Dynamical range: 0-100° C.

USE OF CHANNELING RADIATION IN CRYSTALS FOR INTENSE POSITRON BEAMS

- TEST AT KEK: RESULTS
- * ENHANCEMENT IN PHOTON PRODUCTION : ROCKING CURVE
- Using the photon detector (diamond)
- a 2D angular scan provided the rocking
- curves, on which the crystal alignment
- is based. The enhancement is slightly
- larger than 2.

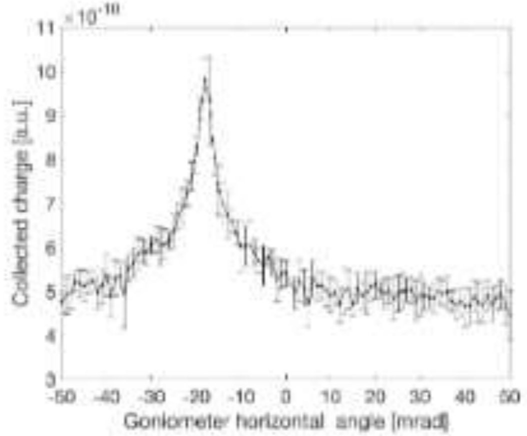
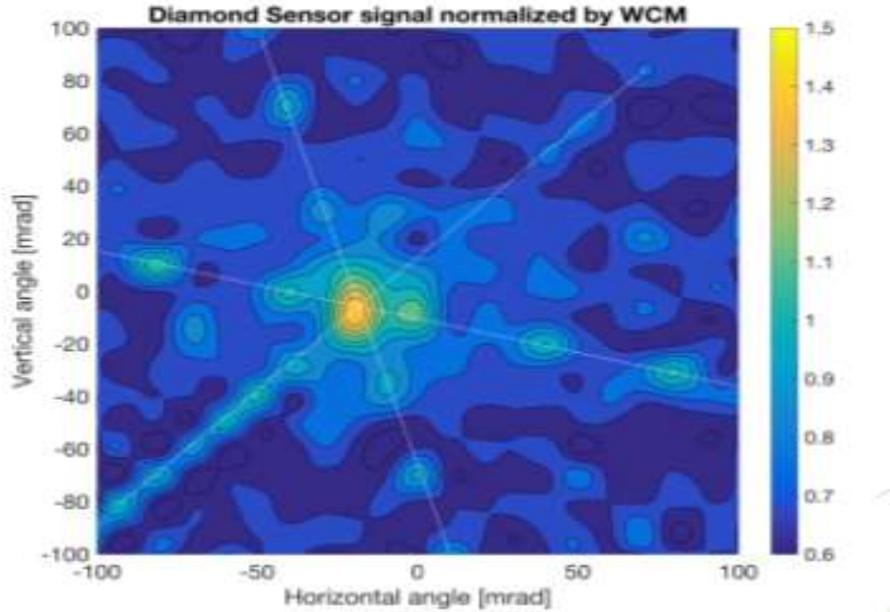


Figure 4: Rocking curve measured by the diamond sensor. Collected charge by the diamond sensor is plotted as a function of the goniometer rotational angle.

USE OF CHANNELING RADIATION IN CRYSTALS FOR INTENSE POSITRON BEAMS

- TEST AT KEK: 2D SCAN FOR THE PHOTON DETECTION
- A 2D scan (± 5.7° in θ_x and θ_y)
- associated to the diamond detector
- allowed observation of different
- channeling directions.
- The dimensions of the diamond
- detector were:
- * thickness 500 μm
- * transverse dimensions: 4x4 cm^2



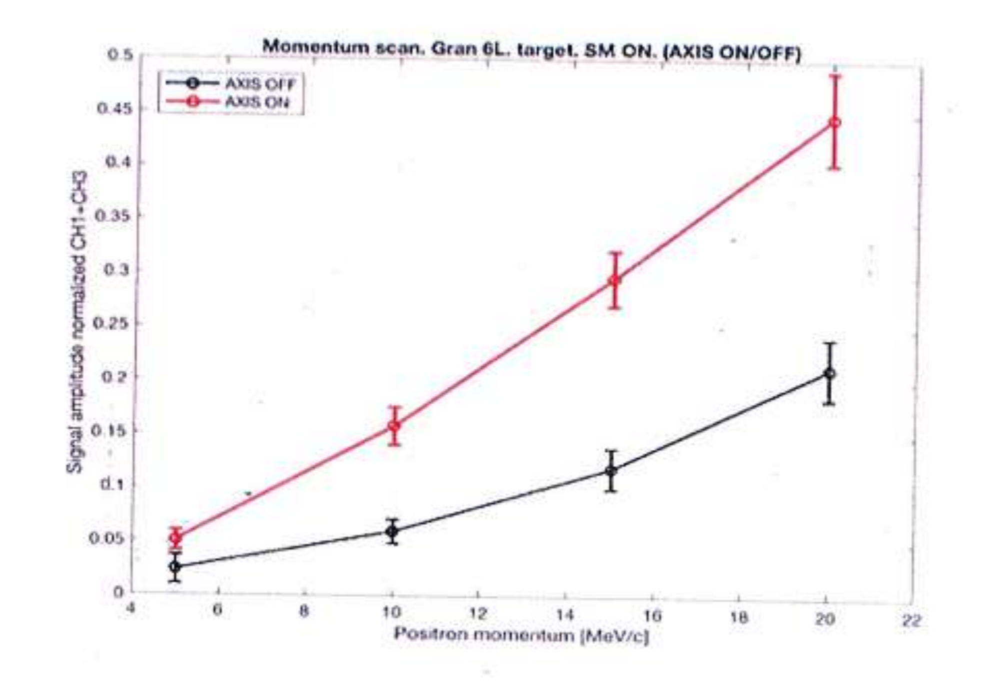
R.Chehab/POSIPOL2017/BINP

Measurements at KEK by V.Kubitsky, I.Chaikovska et al. October 2016

USE OF CHANNELING RADIATION IN CRYSTALS FOR INTENSE POSITRON BEAMS

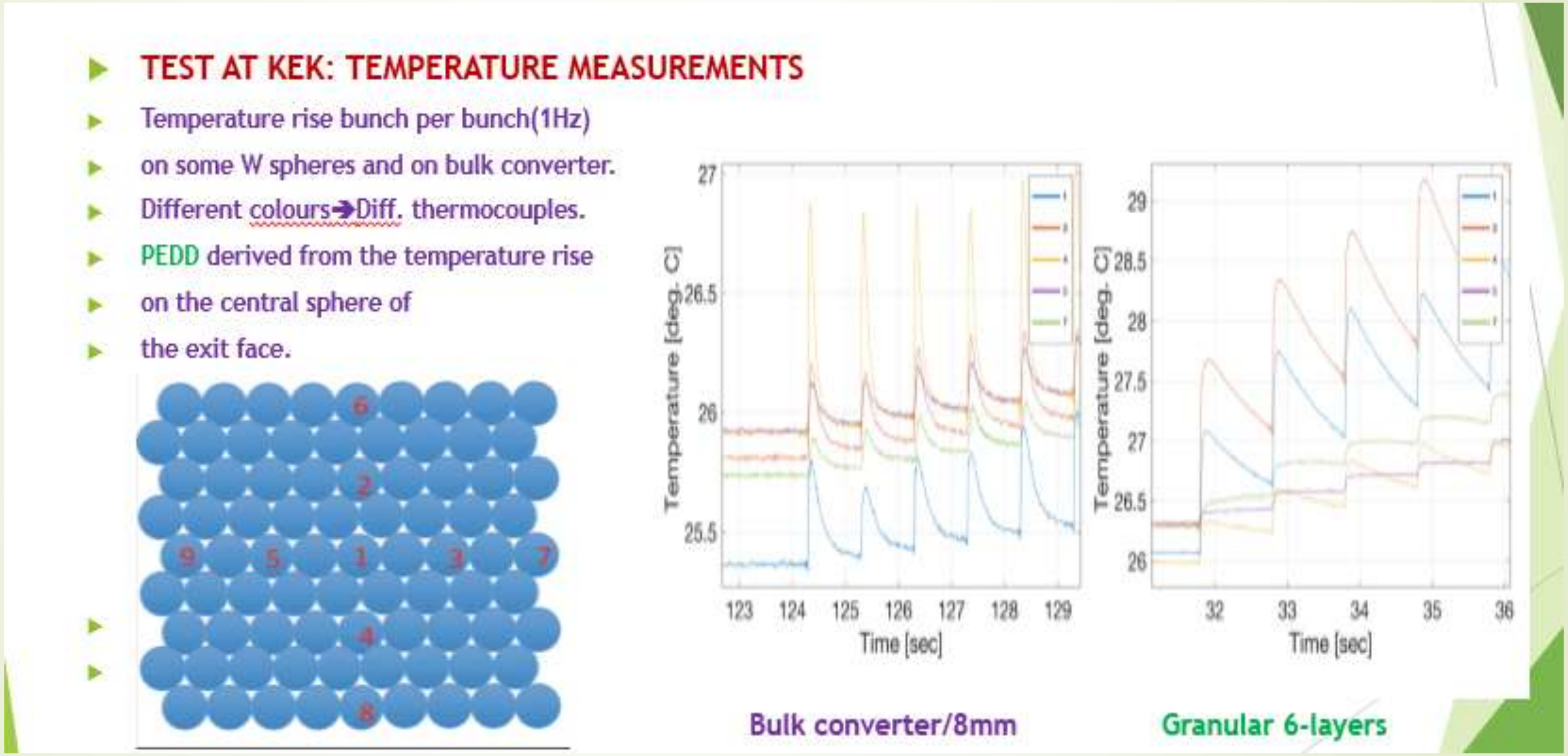
- **TEST OF THE HYBRID POSITRON SOURCE AT KEK: POSITRON YIELD**

Positron yield has been measured for 4 values of positron energy: 5, 10, 15 and 20 MeV. On the figure we present the experimental results for a 6-layers granular converter with the 2 situations: crystal on axis and off axis.. Enhancement in e+ production can be observed in channeling conditions.



Measurements at KEK by I.Chaikovska et al, October 2016

USE OF CHANNELING RADIATION IN CRYSTALS FOR INTENSE POSITRON SOURCES

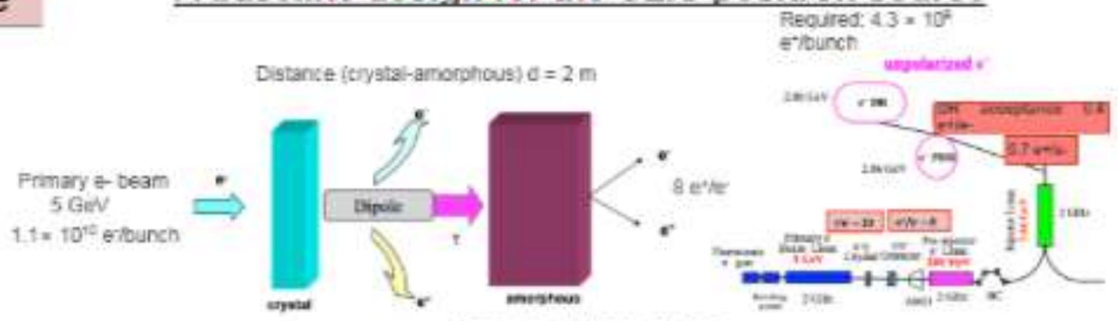


USE OF CHANNELING RADIATION IN CRYSTALS FOR INTENSE POSITRON BEAMS

APPLICATIONS TO e+e- COLLIDERS

Hybrid scheme

A baseline design for the CLIC positron source



Crystal thickness: 1.4 mm
Oriented along the <111> axis

Amorphous thickness: 10 mm

Yield: 8 e+/e- (total) => ~ 1 e+/e- @ 200 MeV => CLIC requirements are fulfilled

Target Parameters Crystal		
Material	Tungsten	W
Thickness (radiation length)	0.4	X_0
Thickness (length)	1.40	mm
Energy deposited	~1	kW

Target Parameters Amorphous		
Material	Tungsten	W
Thickness (Radiation length)	3	X_0
Thickness (length)	10	mm
PEDD	30	J/g
Distance to the crystal	2	m

~ 10 kW
< 35 J/g

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- **2- ILC linear collider**: The high e- beam intensity is leading to some modifications :

Considering an application to ILC, we are proposing after T.Omori to modify the beam time structure before the target, (see figure) recuperating the nominal one after the DR. In that case, macropulses with a duration < 1 µs are impinging on the W spheres. Considering the small spheres dimensions, there is a stress relaxation during the temperature rise due to a shock wave propagation shorter than the heating time (~1 µs) . As an example, for the ILC conditions, the radial stress due to a µs pulse is about 10 times lower than for a Dirac pulse. P. Sievers (CERN) is analyzing such effects (see POSIPOL series)

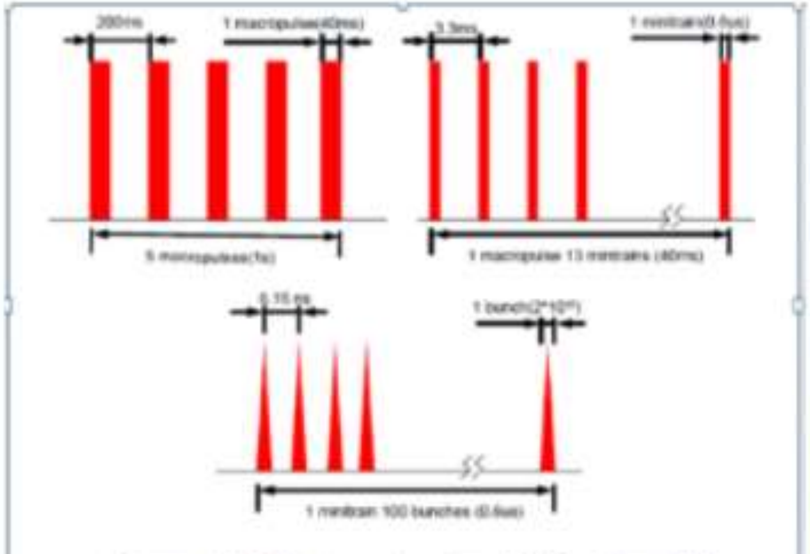

Figure 4.1: ILC beam structure. KEK scheme[42]

Studies on thermal shocks have been carried out by Song Jin (IHEP) and Peter Sievers (CERN).

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- ILC Linear collider: results of simulations
- Granular target: 6 layers
- Total positron yield of
- about ~14 e+/e-
- Deposited energy of ~400 MeV/e-
- Energy deposition density
- of about ~1.4 GeV/cm^3 /e-

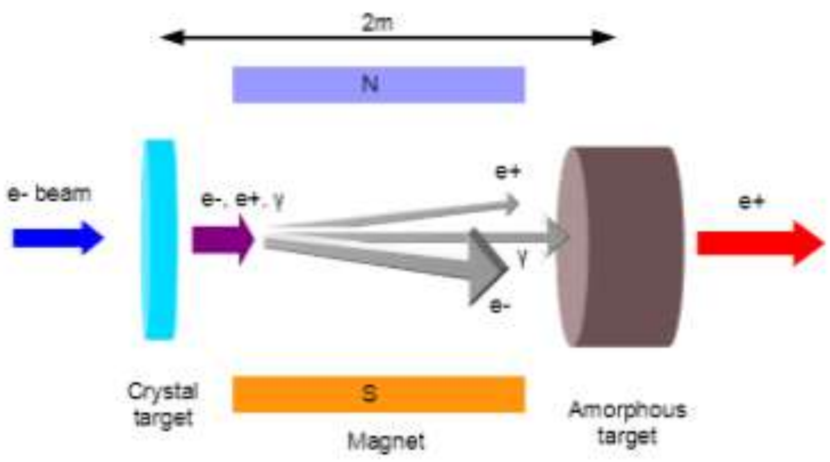

Figure 5.1: Hybrid scheme using crystal and granular target for ILC.

W crystal <111>, 1 mm thick
Incident energy: 10 GeV

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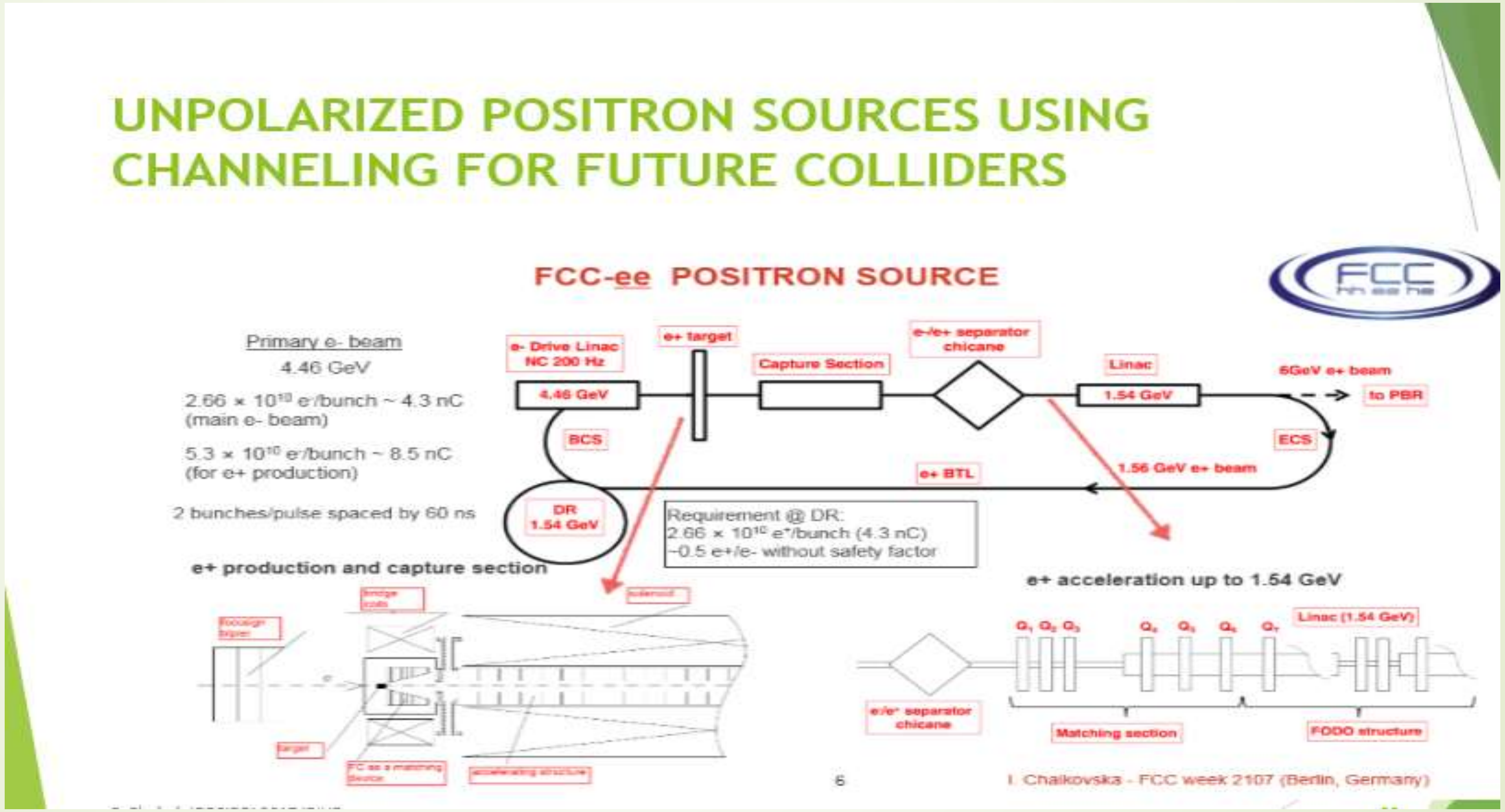
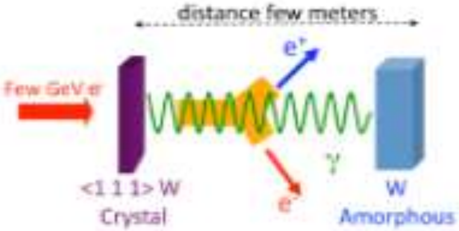


USE OF CHANNELING RADIATION IN CRYSTALS FOR INTENSE POSITRON BEAMS

Positron Sources

1) Conventional positron target: bremsstrahlung and pair conversion

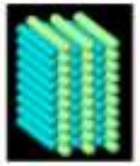
- Classical e+ source.
- It was employed to produce e+ beam at the existing machines (ACO, DCI, SLC, LEP, KEKB…).



2) Hybrid positron target: Two-stage process to generate positron beam. Channeling (crystal target) and pair conversion (amorphous target)

- Use the intense radiation emitted by high energy (some GeV) electrons channeled along a crystal axis => *channeling radiation*.
- Charged particles are swept off after the crystal target => the deposited power and PEDD (Peak Energy Deposition Density) are strongly reduced.
- Granular target can provide better heat dissipation associated with the ratio Surface/Volume of the spheres and the better resistance to the shocks.

Recent idea: to replace the bulk target-converter by a **granular** one made of **small spheres**.



Several experiments had been conducted to study the hybrid e+ source (proof-of-principle experiment in Orsay, experiment @ SLAC, experiment WA 103 @ CERN and experiments @ KEK).

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A SOLUTION FOR FCC-ee BASED ON CLIC SOURCE

Hybrid scheme

- **Flux Concentrator (FC):** peak field is 6 T, DC solenoid field is 0.5 T, length = 20 cm, aperture 40 mm.
- **Accelerating structures:** L-band 2GHz, 25 MV/m, aperture 30 mm.

	@ 200 MeV	@ 2.86 GeV
e+ yield, Ne+/Ne-	0.98	0.97
Emittance norm, µm rad	9	9

☞ CLIC e+ source design seems compatible with the FCC-ee requirements => optimisation with FCC-ee beam parameters.

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- A COMPARISON BETWEEN THE TWO OPTIONS: CONVENTIONAL/HYBRID : FCC
- General conditions; E-=5 GeV; σ =2.5 mm; bunch q = 8.5nC; pulses of 2 bunches at 200 Hz; beam power: 15 kW.

Kind of source	Deposited energy	PEDD
Conventional 4.5 Xo	2.7 kW (17%)	2.1 J/g
Hybrid-Compact	1.2 kW (8 %)	1 J/g
Hybrid-Granular(6-layers)	0.85 kW	0.6 J/g

- For the sake of comparison the incident electron energy has been taken as 5 GeV instead of 4.46 GeV, due to available results at 5 GeV.

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- PRELIMINARY CONCLUSIONS
- * The hybrid positron source using channeling to enhance photon generation and henceforth positron production has been investigated and experimented successfully at CERN and KEK. Its use in linear colliders, where the high intensity is a challenge, can be considered, as shown for CLIC where it has been chosen as the baseline. For ILC, its remains an interesting solution because the deposited energy in the converter as the PEDD are lower than the equivalent (same yield) conventional scheme. A cooling system for both the crystal and the converter are foreseen. Concerning the circular colliders, as FCC-ee, even if the deposited energy and the PEDD are much less a problem because of the lower intensity, it presents still an advantage for these two parameters with respect to the conventional solution.

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- This activity has been developing through a large collaboration involving: LAL, IPN-Lyon, CERN, BINP-Novosibirsk, TPU-Tomsk, KEK, Hiroshima University, KIPT
- A particular tribute must be given to our colleagues and friends of Novosibirsk with the theoretical group (V.N. Baier^{+}, V.M.Katkov, V.M. Strakhovenko^{+}) and the experimental group of SND guided by S.Serednyakov. Fructuous collaboration with A.P.Potylitsin and his group was helpful. Interesting exchanges with the theoretical group of KIPT with N.Shulga were appreciated. The effective collaboration with KEK allowed the experiments on positron sources based on channeling to go ahead, thanks to T.Suwada, M.Satoh, T.Kamitani, K.Furukawa and others.
- In LAL and IPNL, many people have been involved when these studies started (X.Artru, F. Richard, F.Couchot, R.C.,M.Chevallier, J.Remillieux, J-C.Poizat, D.Dauvergne, R.Kirsch); later, A.Variola, A.Vivoli, O.Dadoun, I.Chaikovska, H.Guler and the PhD student from IHEP: C.Xu. In CERN, P.Sievers is continuing his very helpful collaboration.
- This activity is requiring very opened and intense collaborations.

SPECIAL THANKS TO IRYNA CHAIKOVSKA WHO IS LEADING, NOW, THE R&D ACTIVITIES ON POSITRONS AT LAL AND TO XAVIER ARTRU WHO IS FOLLOWING THE THEORETICAL ASPECTS OF THIS ACTIVITY

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- **BACK UP SLIDES**

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RADIATION DAMAGE EXPERIMENT AT SLAC

A 0.3 mm W crystal has been installed upstream of the SLC positron converter. It was irradiated during a period of 6 months. Incident electron intensity as beam position and dimensions on the crystal were continuously controlled.

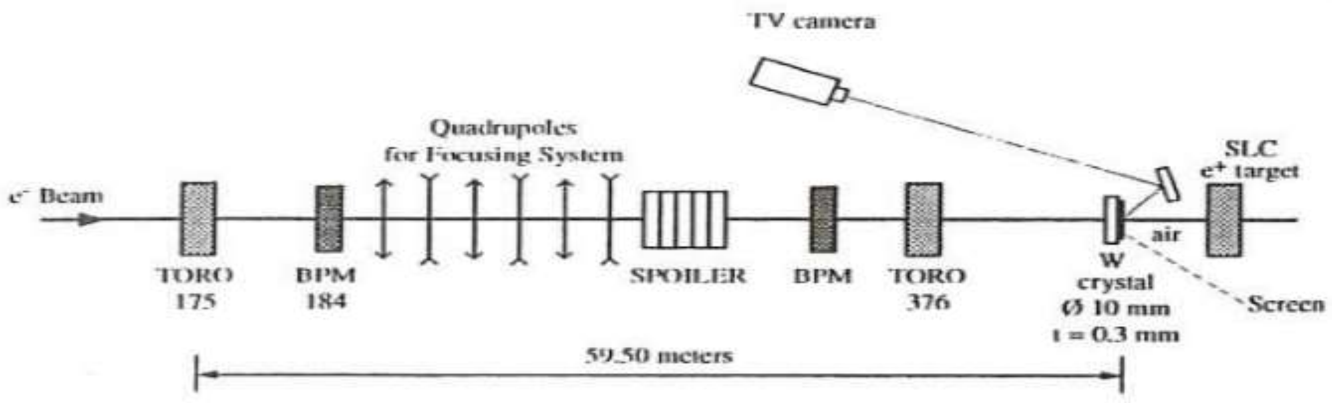

Figure 3: The SLC experimental set-up

Ref: R.Chehab et al. Proceedings of EPAC 1998 Conference , Stockholm, june 1998

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RESULTS OF THE CRYSTAL IRRADIATION AT SLAC

The SLC beam: E-= 29.5 GeV
average intensity: 2.5×10^{10} /pulse
Frequency: 10 and 30 Hz
Integrated intensity (6 months): 1.2×10^{19} e-
Spot area on the crystal: 6.2 mm^2
Total fluence: 2×10^{20} e-/cm^2

Analysis:
X-ray and γ analysis have been operated by diffractometry methods at the Max-Planck Institue of Stuttgart, before and after irradiation. No modification in the mosaic spread of the crystal was observed. The result of the measurement done after irradiation ids shown. The damage threshold should be higher (for e-).
That fluence corresponded to the level of appearance of damages on a Si crystal hitted by 28 GeV and 450 GeV protons (BNL & Fermilab)

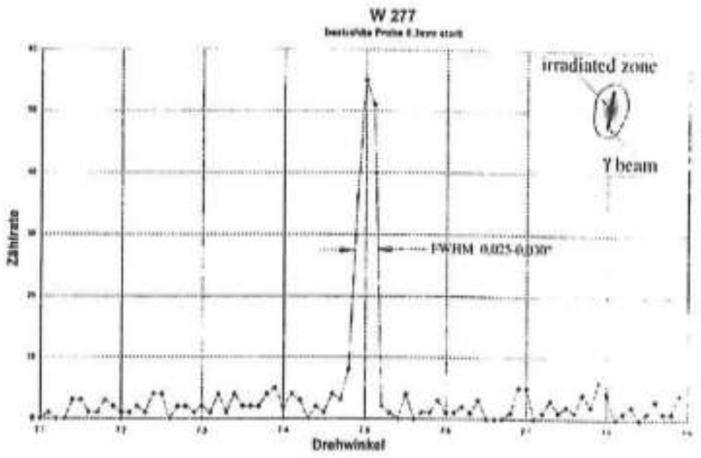

Figure 4: Mosaic distribution function of sample C2 obtained by γ-diffractometry. The γ beam is on the irradiated zone.

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TEST AT KEK OF A Si CRYSTAL WITH HIGH INCIDENT INTENSITY

Tests have been operated at KEK with a Si crystal 2.55 mm thick submitted to a 8 GeV and single bunch e- beam.
Positron yield was measured in function of the bunch charge, growing from 0.09 to 1.9 nC. The range of bunch density was (0.15-1.2) x10^4 A/cm^2
The results show that the positron yield increases linearly with the charge: no abnormal behavior of the crystal.
The fluence was high enough >10^{22} e-/cm^2

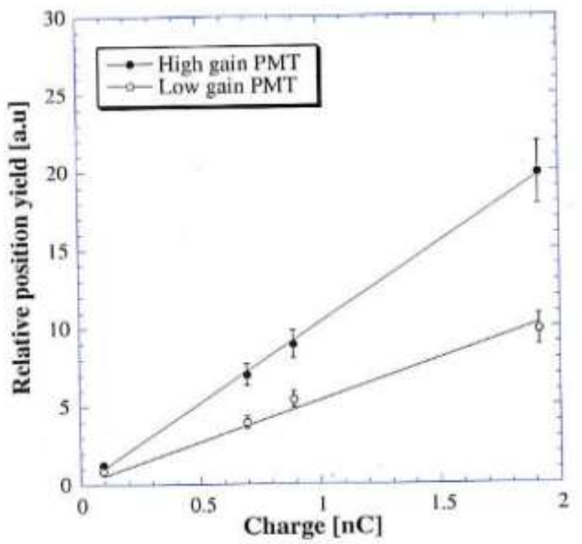

Fig. 6. Positron yields as a function of the bunch charge at a positron momentum of 20 MeV/c. The solid curves drawn through the data are the fitted linear functions.

Ref: T.Suwada et al. NIMB 252 (2006)142-147

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INFLUENCE OF THE CRYSTAL TEMPERATURE ON THE POSITRON YIELD

2.2.2 *The Crystal in Warm Regime*

Heating the crystal, with the energy deposited by the shower, makes the thermal vibration amplitude u_1 larger. As the radiation intensity spectrum, in channeling conditions, is a decreasing function of u_1.[5] this intensity becomes lower when the crystal is heated.

We can observe the effects of the temperature on the continuum potentials of the ⟨111⟩ axis (Figure 9). These potentials have been estimated using the expression given by Baier *et al.*[10]

$$U(x) = V_0\left[\ln\left(1+\frac{1}{x+b}\right) - \ln\left(1+\frac{1}{x_0+b}\right)\right], \qquad (8)$$

where

- $V_0 = Ze^2/d = 430$ V, for the tungsten crystal oriented along its ⟨111⟩ axis,
- $x = \rho^2/a_s^2$; ρ being the distance to the axis and a_s, the screening radius,
- $b = 2u_1^2/a_s^2$; u_1 being the thermal vibration amplitude,
- $x_0 = S/\pi a_s^2$; S being the entire area associated with individual axis,
- u_1 is increasing with the temperature; its values is derived from Gemmel[11] and given in Table I.

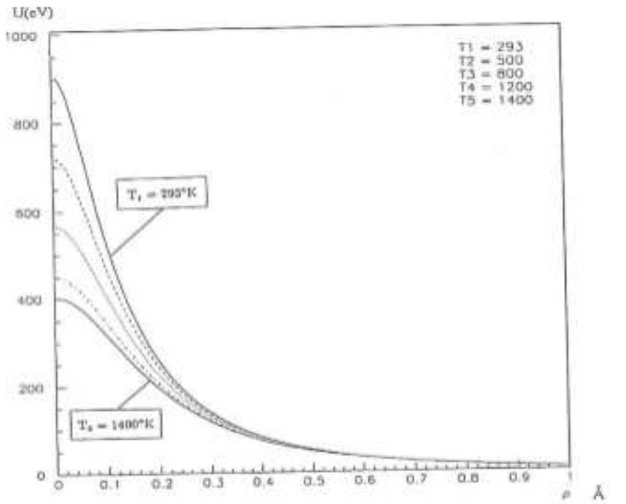

FIGURE 9 Continuum potentials for the (111) axis of the tungsten crystal. The temperatures are expressed in K.

TABLE I Thermal vibration amplitude (u_1)

T (K)	400	500	600	700	800	1000	1200	1400
UTHERM (u_1)	0.058	0.065	0.071	0.077	0.082	0.091	0.100	0.109

Ref: X.Artru et al. Particle Accelerators vol.59,(1998)19-41