INTENSE PRODUCTION OF e+e- PAIRS WITH RADIATION FROM CRYSTALS

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- **INTRODUCTION**
- **Future Linear Colliders are requiring intense positron sources with good emittance. Since 20 years french physicists (LAL, IPNL) associated then to russian physicists (BINP, Tomsk) have proposed positron sources using channeling radiation in crystals. An experiment performed at CERN (WA 103) and experiments carried out at KEK have shown the interest of such sources. Recently this kind of source has been chosen for the CLIC positron source baseline.**

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- **THE RADIATIONS IN CRYSTALS**
- **A charged particle passing through a crystal very near to major crystalline planes or axes is channeled and undergoes a periodic motion in the transverse plane. It is then radiating. The channeling radiation intensity depends strongly on the electric potential well values associated to the planes or axes. The energy spectrum shape is depending on the particle energy: for low energy (some MeV) a quantum mechanical treatment gives radiative transitions between two eigenstates of the transverse potential; for high energies (> 1 GeV) the treatment may be classical and the spectrum is almost continuous. We shall consider incident electron energies in the GeV range. The channeling condition is**
- $\psi < \psi_c = \sqrt{(2U/E)}$ **where ψ is the incident angle, U the crystal potential and E the particle energy.**

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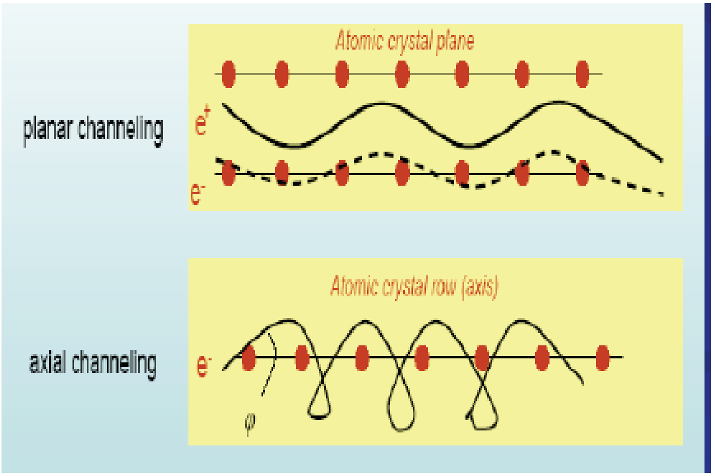
- **RADIATIONS IN CRYSTALS**
- **1- CHANNELING RADIATION**
- Planar and axial channeling are
- represented on the figure; the
- behavior is different for e+ and e-



2-COHERENT BREMSSTRAHLUNG

At angles larger than the critical angle the e- crossing strings or planes at regular steps emits radiation with interference effects; oscillation period is λ

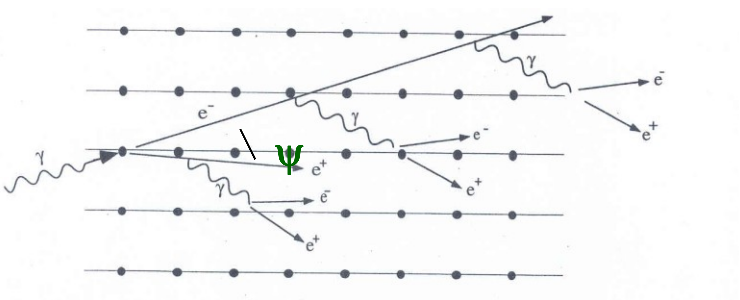


Figure 13 : Pair production associated to coherent bremsstrahlung.

λ period of oscillation ~ a/ψ ; a=interatomic distance and ψ, incidence angle _ λ << channeling period ➔ γ harder with CBS than with CHR

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- **PAIR CREATION IN STRONG FIELDS**

  - A new process, pair creation in strong fields, occurs at very small - glancing - angles of the photons on the atomic strings. This process becomes significant at high values of the incident photon energy and for large enough crystal fields.

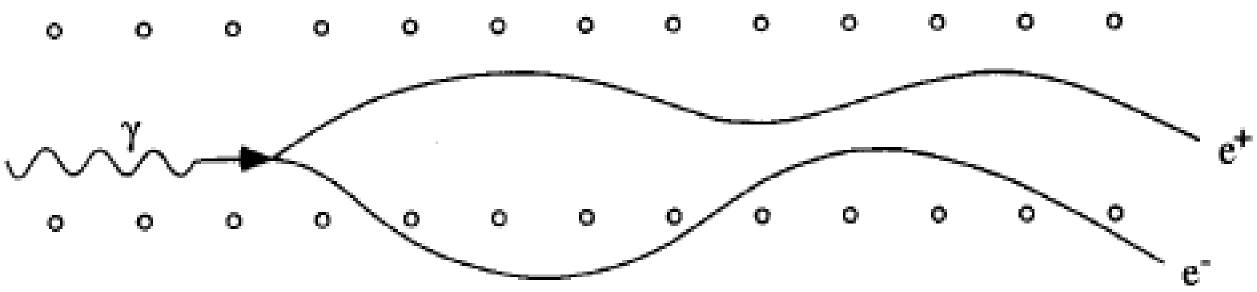

Figure 14 : Pair creation in strong field.

Some threshold value for the incident photon beam : about 20 GeV for W crystal at normal temperature.

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THE RADIATIONS IN CRYSTALS

As the potential well values are much higher for the crystal axes than for the crystal planes (one order of magnitude at least) we choose axial channeling. The expected photon energy is given approximately by:

$$\omega = 2\gamma^2 \Delta E_T$$

where ΔE_T (~ a few eV) is the difference between the initial and the final transverse energy levels. For a 10 MeV e-, the generated X- ray is of some keV. With GeV e- beams, the spectrum is almost continuous: tens of MeV γ-rays can be obtained.

The particle may be dechanneled after many scatterings and generate bremsstrahlung radiation as in amorphous media.

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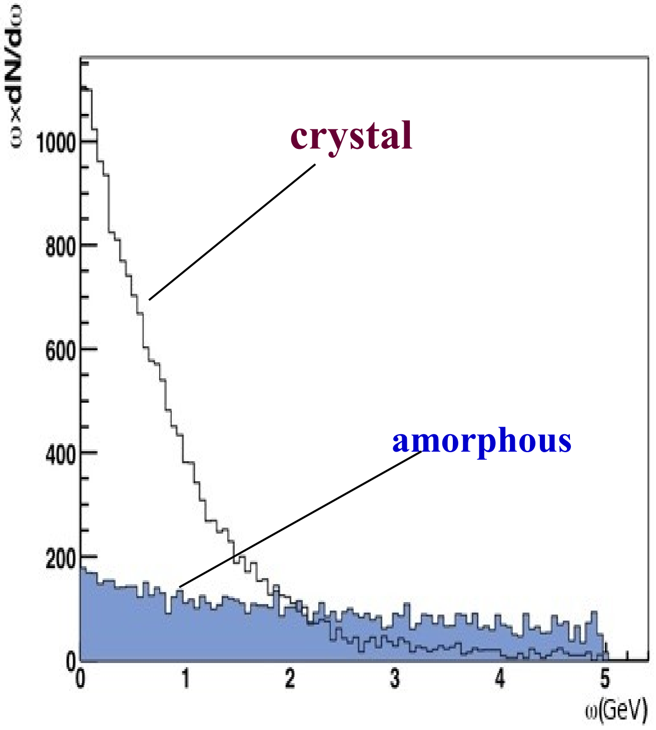
THE RADIATION SPECTRUM

The channeling radiation and quasi-channeling radiation due to above barrier particles are much softer than that of the Bremsstrahlung as illustrated on the figure, where the vertical scale is ω.dN/dω and the horizontal scale, ω. The bremsstrahlung dependence on ω is 1/ω and with this vertical scale has an almost uniform shape.

Incident energy: 8 GeV; crystal thickness, 1 mm.



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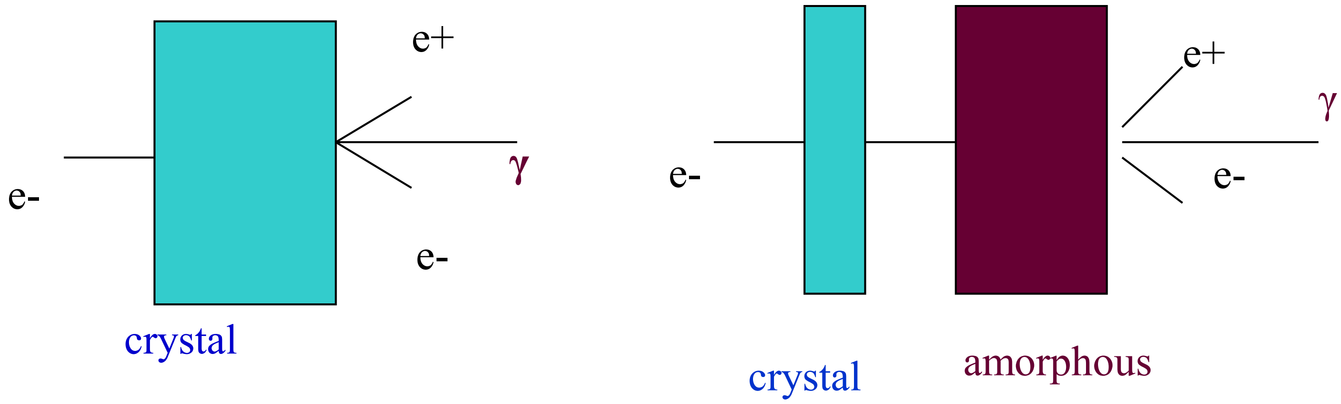
- **THE CHOICE FOR e+ SOURCES: AXIAL CHANNELING**
- **The choice of the crystal: W aligned on its <111> axis where the available potential is ~ 1 kV at room temperature.**
- **Two schemes are possible:**
- **1) A compact target (radiator & converter)→ thick crystal**
- **2) An Hybrid target (radiator and converter, separated)**



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THE CERN EXPERIMENT (WA 103)

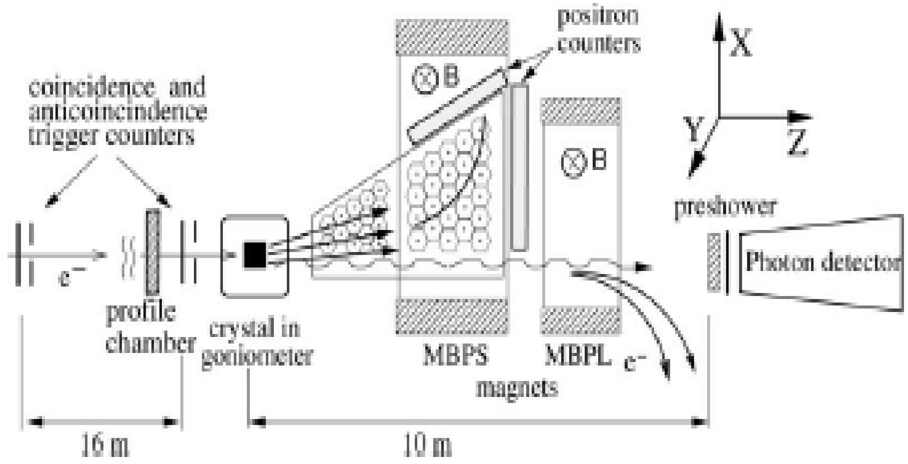

Fig. 1. The setup scheme. Drift chamber in two parts. DC1 is outside the magnetic field. DC2 is in the magnetic field of MBPS magnet. MBPL is the sweeping magnet.

The experiment used compact and hybrid configurations. The positron trajectories have been reconstructed in a Drift Chamber. Energy spectra and angular distributions were measured at 6 and 10 GeV; total energy domain scanned was 5 to 40 GeV.

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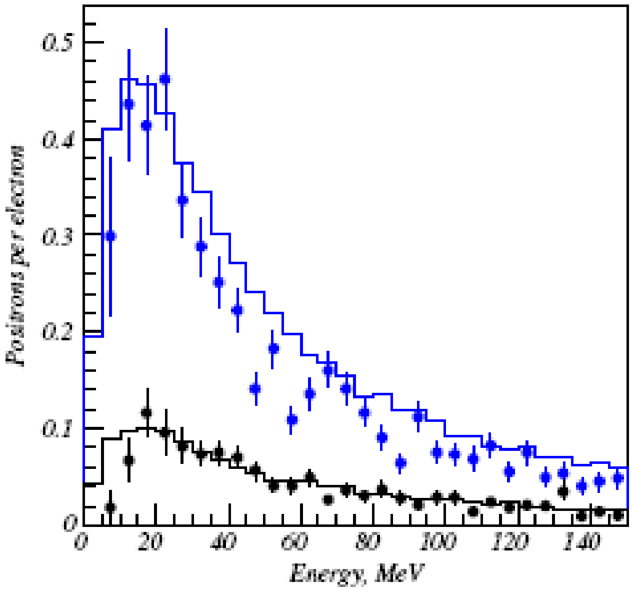
- **SOME RESULTS OF WA 103; data for 10 GeV/4 mm**

Energy spectrum **Angular distribution**



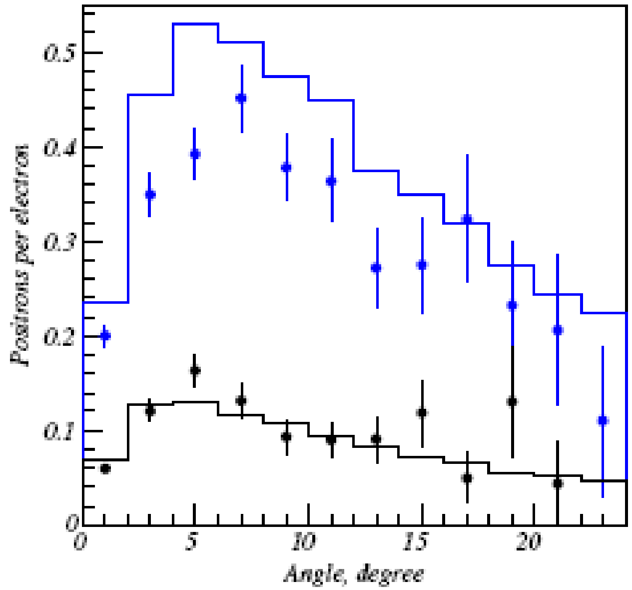


Fig. 11. The positrons horizontal momentum p_h (left) and angular (right) distributions for one incident electron and 4 mm thick target. The electron energy is 10 GeV. The points with error bars are the experimental data. The histograms are the simulated spectra. The upper histograms and points on the 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.

Positron yield enhancement for 4 mm crystal (w.r.t 4 mm amorphous) was > 4

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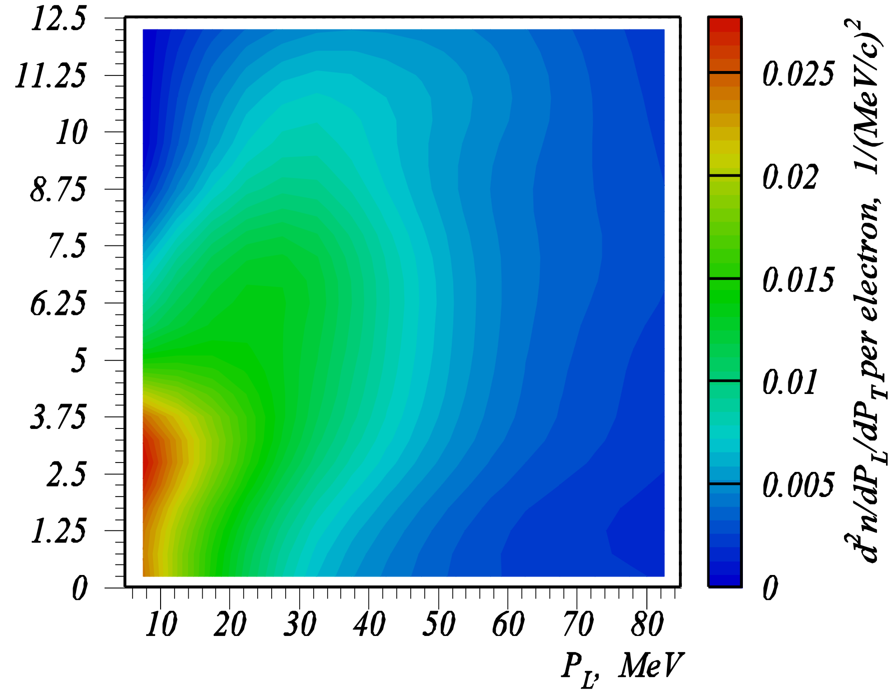
- **SOME RESULTS OF WA 103**

THE EMITTED POSITRONS HAVE BEEN MEASURED IN A (p_L, p_T) DIAGRAM; MOST OF THEM ARE IN A SOFT MOMENTUM REGION AND HAVE A LOW TRANSVERSE MOMENTUM; KNOWLEDGE OF THE MATCHING LENS PROVIDES THE EXPECTED YIELD.

On the figure, we have the case of a 8 mm crystal hit by a 10 GeV electron beam directed along the <111> axis.



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- **SOME RESULTS OF WA 103**
- **The experimental set-up of WA 103 allowed us to:**
- **- determine the energy spectra for different compact crystal targets (4 and 8 mm thick)**
- **- reconstruct the positron phase space in the plane (p_L, p_T)**
- **- compare compact and hybrid configurations; for instance, 8 mm compact and (4-crystal + 4-amorphous). Similar results were obtained.**
- **- determine the total and accepted yields in usual capture configurations.**
- **The measured positron yields have been compared to the simulations and showed good agreement. The obtained values have been determined for different phase space acceptances, depending on the matching systems put after the target. For instance, for usual matching systems with a momentum acceptance of 5 to 25 MeV/c and a transverse momentum acceptance of 8 MeV/c, the number of accepted e+ is ~ 2.5 e+/e-. That allows a yield of 1 e+/e- at the IP.**

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- FROM WA 103 TO A e+ SOURCE FOR LINEAR COLLIDER
- The positron beam characteristics measured with WA 103 provided the yield, and phase space as well as the enhancement in positron production with respect to amorphous targets of the same thickness. The latter was well confirmed by many experiments carried out at KEK. In order to use these promising devices in a linear collider, which implies high intensity and long pulse duration, some aspects, not studied with WA 103, must be investigated:
- * the heating (average and instantaneous)
- * the radiation damage in the crystal due to important
- Coulomb scattering of the electrons on the nuclei

INTENSE PRODUCTION OF e+e- PAIRS WITH RADIATION FROM CRYSTALS

- **POSITRON SOURCE: HEATING**
- **The important energy deposition in the target has 2 aspects:**
- *** Average heating: appropriate cooling can be foreseen**
- *** Instantaneous energy deposition ➔ temperature gradients and shock waves**
- **The average heating of a crystal affects the available potential through the amplitude of the thermal vibration u_1 from which this potential is depending.**
- **The potential decreases by 35 % for ΔT=500° K**

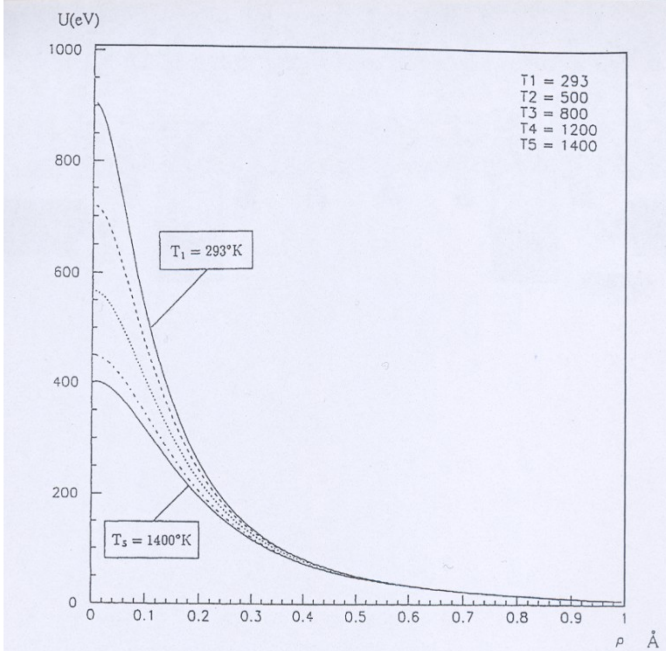

FIGURE 9 Continuum potentials for the ⟨111⟩ axis of the tungsten crystal. The temperatures are expressed in K.

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

Potential variation with temperature

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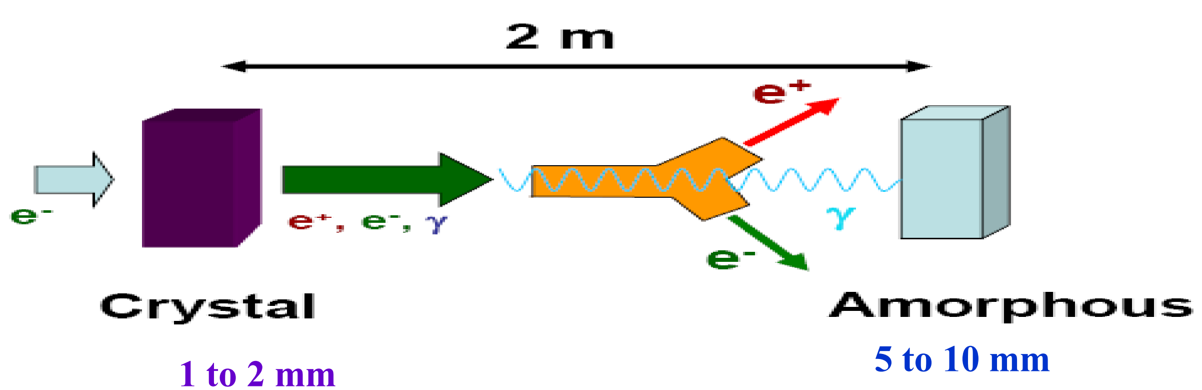
INSTANTANEOUS ENERGY DEPOSITION → PEDD

The energy deposition in the target by the shower components is far from homogeneous leading to thermal gradients and, subsequently, mechanical stresses. Moreover, the instantaneous energy deposition may induce shock waves which appear destructive as in the SLC case. In order to address this issue, an hybrid source combining a thin crystal radiator and an amorphous converter with a sweeping magnet in between has been studied. [R.Chehab, V.Strakhovenko, A.Variola] Allowing only the photons to hit the converter, we lower considerably the Peak Energy Deposition Density (PEDD)



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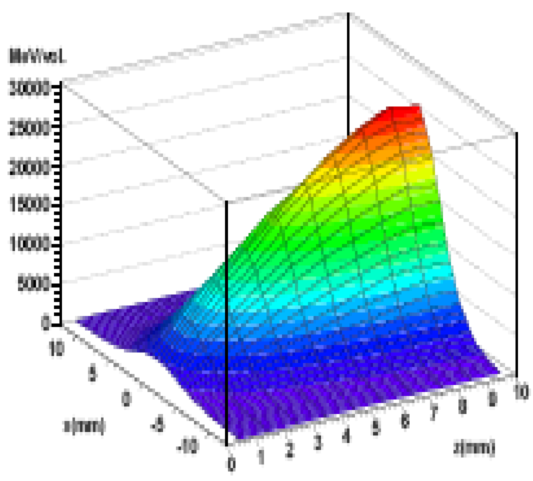
- **THE PEDD**
- **The analysis made after the SLC target breakdown indicated a maximum value for the PEDD (for W) of 35 J/g. So the simulations concerning the energy deposition density were performed in order to check that this limit was not reached.**

The energy deposition density has been calculated dividing the amorphous target in small domains of $2.5 \cdot 10^{-4}$ cm^3. As an example we represent the deposited energy distribution for the case:E-=5Gev; t (am):10 mm The energy density is maximum at the target exit.. In this case it is about 20 J/g

Amorphous target



Crystal: 1.4 mm; distance: 2 meters

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- **THE RADIATION DAMAGE**
- *** Intense Coulomb scattering of shower components on nuclei**
- **→ dislodgements of nuclei from sites with possible cascades**
- *** Define a critical fluence N^{-}/cm^{2} for which the fraction of dislodged atoms can reach 1 % (for instance). For W it is ~ 10^{20}e-/cm^{2}**
- ***Experimental verification (e-) → test at SLAC in 1996; a thin W crystal put before the SLC target and irradiated for 6 months.**
- *** Similar tests with protons at BNL, Fermilab, Protvino, CERN and Si crystal → damages appearing at 4.10^{20}p/cm^{2}**

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- **THE SLAC EXPERIMENT FOR RADIATION DAMAGE**

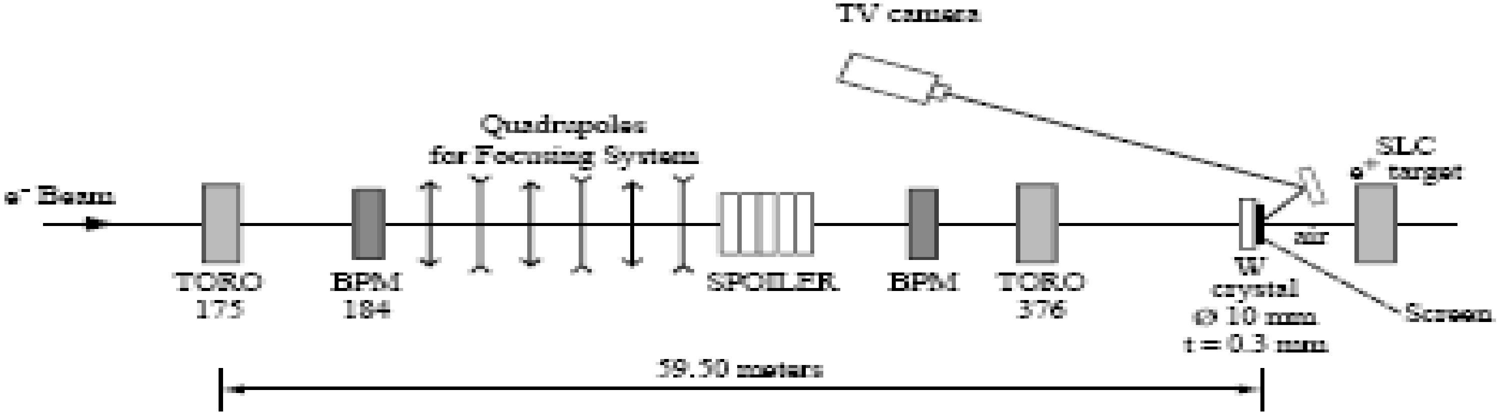

Figure 3: The SLC experimental set-up

A thin tungsten crystal (0.3 mm thick) has been put just before the SLC target and hit by the 30 GeV e- beam during 6 months (1996). Before and after irradiation and for a fluence of 2.10^{20} e-/cm^2 [the integrated intensity being 1.2×10^{19} e-] no damage was observed by γ diffraction analysis with a ^{137}Cs source: the mosaic spread did not change (0.03 degree at FWHM)

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- **SUMMARY & CONCLUSIONS**
- *** The hybrid source using the intense radiation from an axially oriented crystal to create a large number of e+e- pairs in an amorphous converter placed at some distance is very promising for the yield, the phase space and above all for the reduced PEDD.**
- *** Such a system has been chosen as the baseline for CLIC**
- *** Further studies of the hybrid source may concern the thermal behavior, particularly for the fast energy deposition**
- *** Systematic tests are being operated at KEK; results on the e+ yield and enhancement are already available. Thermal observations are under development.**

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- **POSITRON SOURCES USING CRYSTAL EFFECTS**
- **Many persons are collaborating in this field:**
- **IPNL: X.Artru, R.Chehab, M.Chevallier**
- **LAL: O.Dadoun, A.Variola, Chenghai Xu**
- **BINP: V.M.Strakhovenko**
- **CERN: L.Rinolfi, A.Vivoli**
- **KEK: T.Kamitani, T.Omori, T.Suwada, J.Urakawa**
- **Hiroshima U. : T.Takahashi**
- **IHEP: G.Pei (and C.Xu)**
- **Most of the works were the result of a franco-russian (IPNL—LAL-BINP) collaboration and of a japanese team; a straigth collaboration between the franco-russian and japanese teams started since 10 years. The support and participation from CERN are greatly appreciated. IHEP, with a PhD student at Orsay is sharing the efforts**