# FROM BREMSSTRAHLUNG TO CHANNELING RADIATION: A PROMISING WAY FOR POSITRON GENERATION

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**FROM BREMSSTRAHLUNG TO CHANNELING RADIATION:**
   **A PROMISING WAY FOR POSITRON GENERATION**

▶ **OUTLINE**

▶ **1) INTRODUCTION**

▶ **2) BREMSSTRAHLUNG IN THICK TARGETS  FOR POSITRON SOURCES**

▶ **3) PHOTON GENERATORS FOR POSITRON PRODUCTION**

▶ **4) CHANNELING RADIATION FOR POSITRON PRODUCTION**

▶ **5) SUMMARY AND PERSPECTIVES**

# FROM BREMSSTRAHLUNG TO CHANNELING RADIATION: A PROMISING WAY FOR POSITRON GENERATION

- ## 1) INTRODUCTION

- Interest on positron sources appeared, first, for **fixed target experiments** ➔ possibility to get monochromatic gamma-rays by positron annihilation.

- The interest strengthened with the strong development of colliding beam facilities

  ➔ **high level of energies in CM** allowing to reach high energy new particles ( $J/\Psi$, $W^{\pm}$, $Z_0$, Higgs bosons,…)

- The requirements on positron beams for the e+e- colliders are also determined by the luminosity,

$$L = f_c\, n_1 n_2\, / 4\pi \sigma_x . \sigma_y$$

  where $f_c$ is the collision frequency, $n_1$, $n_2$ the number of particles in each beam, $\sigma_x$ and $\sigma_y$ the rms transverse beam sizes , assuming that both e+e- beams have identical transverse shapes.

- These requirements may be summarized by **high intensities** and **low emittances** .

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▶ **2) THE CONVENTIONAL SCHEME: BREMSSTRAHLUNG & THICK TARGETS**

INCIDENT ELECTRONS ON HIGH Z

TARGET MATERIAL DEVELOP AN

ELECTROMAGNETIC SHOWER

EMITTING BREMSSTRAHLUNG

PHOTONS WHICH MATERIALIZE IN

ELECTRON-POSITRON PAIRS



Fig. 1. Simplified schematic of the initial portion of an EM cascade shower.
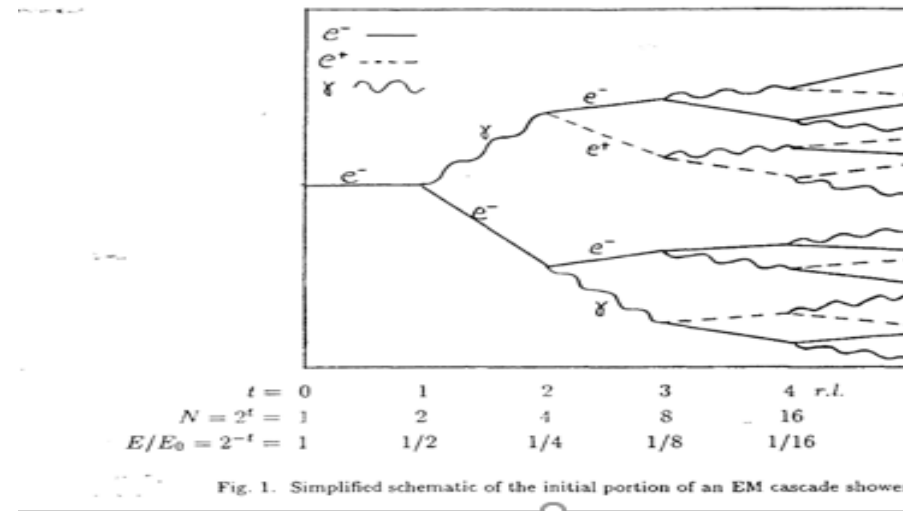
The conventional scheme has been widely used for experiments with fixed targets and also for e+e- colliders. The positron yield depends on the incident electron energy and on the target thickness:

when E- increases ➔ positron yield increases also
when target thickness L increases ➔ positron yield increases also up to the maximum of the transition curve.

➔ high incident energies and thick targets to get high e+ yields

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- **CHARACTERISTICS OF THE CONVENTIONAL SOURCES**

- **The requirements for positron sources dedicated to e+e- colliders in order to get a high luminosity:**

  - **- high intensity (high E- and thick targets)**

  - **- low emittance ( small transverse dimensions for the incident e- beam)**

- **These two conditions are leading to important heat load in the target and also to high energy deposition density ➔ thermal and mechanical stresses ➔ risks of breaking for the target (see SLC target)**

- **MAY BE: the solution is to have an intense photon beam and a thin target**

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## ELECTROMAGNETIC SHOWER DRIVEN BY A PHOTON BEAM
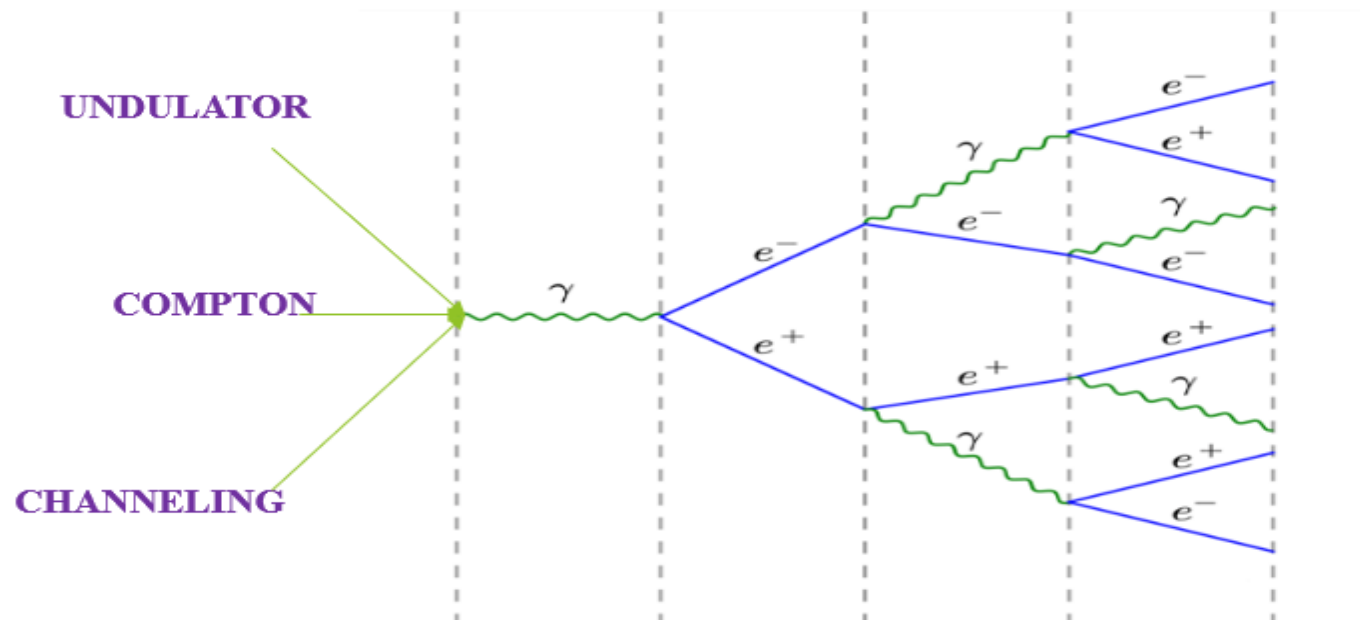
# FROM BREMSSTRAHLUNG TO CHANNELING RADIATION : A PROMISING WAY FOR POSITRON GENERATION

## 3) PHOTON GENERATORS FOR POSITRON PRODUCTION

▶ Photons are produced through electromagnetic radiation of relativistic electrons, often in periodical structures/fields. Polarization may be possible. The ways:

▶      * **Magnetic undulators/wigglers:**

        # Planar wiggler ➔ : chosen for TESLA –NC option ( to avoid large heat loads on target)

        # Helical undulator➔ circular polarization : chosen for TESLA-SC option and ILC

     * **Laser-Compton backscattering:** circular polarization with circularly polarized laser

▶     Considering the helical undulator and the laser Compton back scattering both are involving an helical motion for the electrons. The formalism to describe the electron dynamics and the radiation is similar:

( see V.N.Baier, et al: « Radiation of relativistic particles moving quasiperiodically in JETP B 53 (1981)688 and V.M.Strakhovenko et al « Generation of circularly polarized photons for a linear collider polarized positron source in NIM A 547(2005)320)
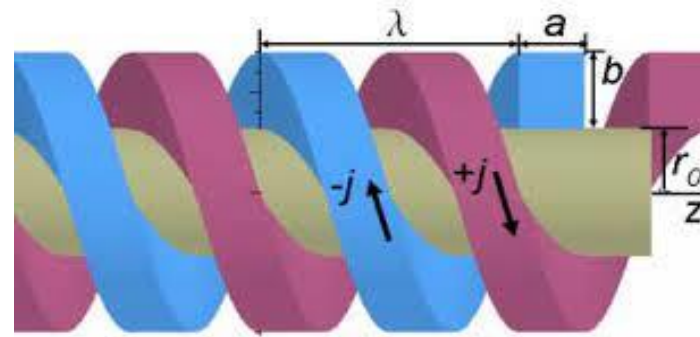
▶      * **Channeling radiation in oriented crystals**

# FROM BREMSSTRAHLUNG TO CHANNELING RADIATION: A PROMISING WAY FOR POSITRON GENERATION
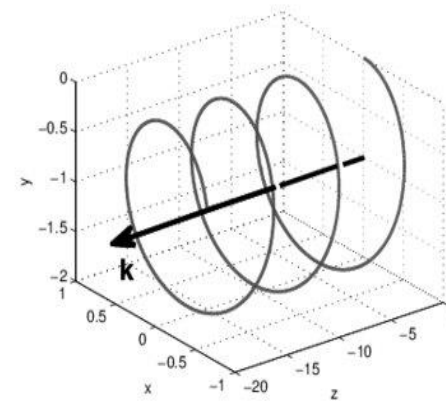
- ## PHOTON GENERATORS FOR POSITRON PRODUCTION

- ### HELICAL UNDULATOR

- The electron beam has an oscillatory trajectory

- with the same period as the the undulator. The

- circularly polarized photons are emitted with a

- wavelength: $\lambda = (\lambda_u/2\gamma^2)[1+K^2 + (\gamma\theta_{phot})^2]$ where

- $K=eB\lambda_u/2\pi mc$ (undulator strength)

- ### LASER-COMPTON

- The electron motion is also helical with the plane

- wave field of the laser. The edge of the Compton

- backscattered photon spectrum is roughly given by

- $\omega_2 = 4\gamma^2\omega_1$ where $\omega_1$ and $\omega_2$ are the laser and

- backscattered photon frenquencies, respectively.

# FROM BREMSSTRAHLUNG TO CHANNELING RADIATION: A PROMISING WAY FOR POSITRON GENERATION√

▶ **PHOTON GENERATORS FOR POSITRON PRODUCTION**

▶ **Channeling radiation in oriented crystals**

▶ # Planar channeling ➜ weak potential

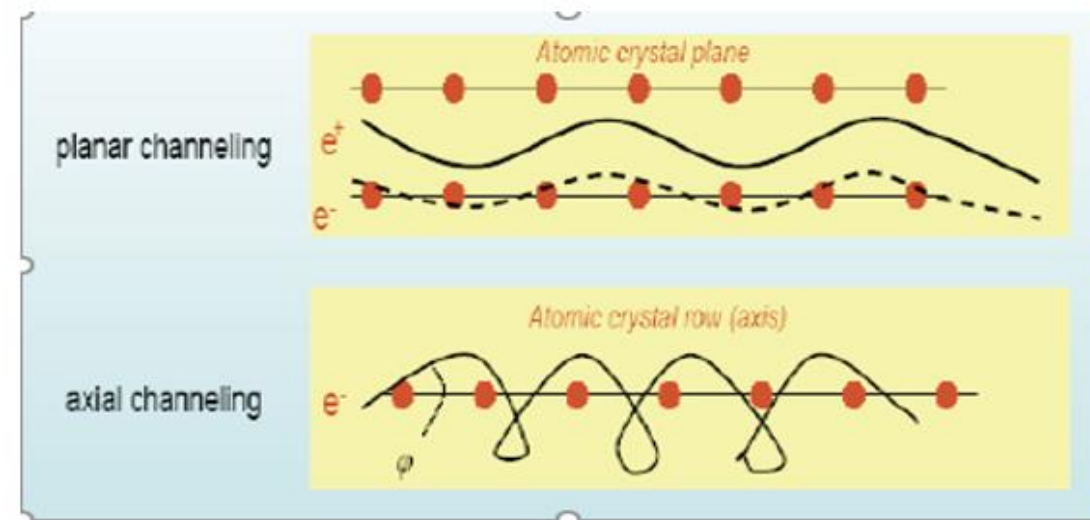# Axial channeling ➜ strong potential

▶ Channeling condition:

▶ Angles of electrons w.r.t atomic rows:

▶ $\Psi < \Psi_c = \sqrt{(2Uo/E)}$

▶ where Uo ➜ potential of atomic rows

▶ E, electron energy

▶

▶ The e- motion in the crystal fields is not as regular as in undulators and laser waves➜rosette ➜ chaotic trajectories

# FROM BREMSSTRAHLUNG TO CHANNELING RADIATION :
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▶ **PHOTON GENERATORS FOR POSITRON PRODUCTION: THE YIELD**

**\* UNDULATOR**

➔ **The number of photons is proportional to $K^2$ with K= K=eB $\lambda_u$ /2πmc and to N, the number of periods: the higher B and N, the higher the yield**

**\* LASER-COMPTON**

➔ **The yield is proportional to $(\lambda_w)^2$ , the square of the laser wavelength and to the laser power density (Watts/cm$^2$). As the Compton cross-section is weak, one needs high laser power densities using, for instance, high finesse optical cavities.**

**\* CHANNELING**

▶ ➔**The energy radiated and the number of photons depend on the kind of crystal (Z) (material and orientation)**

**High Z ➔ high atomic potential➔ large radiated energy➔ high photon yield**

**Referring to V.N.Baier et al in Phys.Stat.Solidi 133 (1986)583-592**

**The W crystal (<111>) has a rather strong atomic potential (937 eV at normal temperature and 1255 eV at 77° K)**

**whereas Si crystal (<110>) has a 140 eV potential at normal temperature**

**The Diamond crystal <111> has a potential of 103 eV at normal temperature.**

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▶ **PHOTON GENERATORS FOR POSITRON PRODUCTION: ENERGY SPECTRUM**

▶ **\* UNDULATOR**

▶ wavelength: : $\lambda = (\lambda_u/2\gamma^2)[1+K^2 + (\gamma\theta_{phot})^2]$ ; as $\lambda_u$ is relatively large (~cm), high $\gamma$ needed; needs of **150 GeV** e- to get a first harmonic at 10 MeV. This energy was chosen for VLEPP (Balakin & Mikhailichenko)

▶ **\* LASER-COMPTON**

▶ The backscattered photon has a frequency: $\omega \le 4\gamma^2\omega_{laser}$ ; it is possible with visible laser photons (Nd:YaG) and **1 GeV** electrons to obtain $\gamma$ with enough energy (~30 MeV) for e+e- pairs creation

▶ **\* CHANNELING**

▶ The energy of the radiated photon is approximately given by: $\omega = 2\gamma^2\Delta E_T$ ; where $\Delta E_T$ is the transverse energy loss between channeled states (some eV); for $\Delta E_T = 5$ eV, and $\gamma = 2000$ **(1 GeV)** 40 MeV photons can be created providing enough positron energies.

▶ These large differences between the incident energies are due to the large ratio of respective wavelengths ( about a factor of 4 decades between the undulator ($\lambda$=1cm) and the laser-compton or the channeling (about 1 μm).

▶

▶

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▶ **PHOTON GENERATORS FOR POSITRON PRODUCTION: POLARIZATION**

▶ **\* UNDULATOR:**

   **# Planar undulator➜ linear polarization**

   **# Helical undulator➜ circular polarization**

▶ **\* LASER-COMPTON**

   **# Polarization related to the laser; for e+e- collider, circular polarization of the laser is chosen for longitudinal polarization of the positrons**

▶ **\* CHANNELING:**

   **# linear polarization with planar channeling or with coherent bremsstrahlung: with axial channeling no polarization considered**

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▶ **PHOTON GENERATORS FOR POSITRON PRODUCTION: THE CHALLENGES**

▶ **\* UNDULATOR: in order to obtain large yields ($\gamma$/e-) large number of periods are needed: ➔ long undulators (200 to 300 m )➔ as the apertures are small enough (< cm), alignment is critical. Also risk of wake fields with the small apertures.**

▶ **\* LASER-COMPTON: High laser powers are needed to compensate low Compton cross section. ➔ optimized optical cavities with great finesse**

▶ **\* CHANNELING: to get enough enhancements in photon production➔ channeling conditions with low divergence beams ➔ $\Psi \leq \Psi_c$ ($\Psi_c$ =0.5 mrad for W <111> and E$^-$ =10 GeV) . Also good mosaicity.**

▶ **Needs to control radiation damages:   see next slide**

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▶ **PHOTON GENERATORS FOR POSITRON PRODUCTION: channeling**

\* **Radiation resistance:** the threshold for which an atom can be dislodged from its axis or plane, due to Coulomb scattering, depends on the kind of crystal. Some theoretical estimations have been carried out ( See X.Artru et al, NIM A 344 (1994) 443-454)

The dislodgement is occuring when the energy available for the

damage is larger than the cohesive force of the atom in the lattice.

As an example for the tungsten crystal, the cohesive energy is ~9 eV.

If a large number of incident electrons is hitting the crystal, it could

provoke a significant number of dislodgements. We may define a

quantity: the **fluence** corresponding to the number of incident particles

per unit area. It is then interesting to determine for which fluence a

significant number of dislodgements are occuring. As an example, the fluence

corresponding to 1% of dislodged atoms is 30 times higher for the diamond crystal

than for the tungsten, making the diamond as the best in this domain.

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## DECHANNELING

When the incident electrons are propagating in the crystal they are submitted to incoherent scattering by the atom nuclei and atom electrons. The scattering angle $\theta_s$ may reach and exceed the critical angle of channeling $\Psi_c$ . The distance at which these two angles are equal is the dechanneling length $L_d$ . The thicknesses of the crystals used for positron sources are of the order of mm or more depending on the kind of crystal. They may be considered as thick crystals

Expressions for the dechanneling length of thick crystals are given for the planar and axial case by V.N.Baier et al (Electromagnetic processes at High Energies in oriented single crystals):

$$L_d = (\alpha/2\pi)[2U_0\varepsilon/m^2].L_{rad}$$

As it can be seen the dechanneling length is increasing with the energy $\varepsilon$.

Different simulations and experiments led to an estimation of $L_d$ ~15-20 µm/GeV (see U.Wienands et al. in NIMB (2017) , H.Backe et al in Journal of Physics vol.438 (2013)012017 and B.Azadegan et al. in Radiation Physics and Chemistry 157(2019)84) for planar channeling in Si crystal.

In our case, axial channeling, the incoherent scattering is strong and most of the radiating electrons are above barrier. This can be observed on the rocking curves for photons as for positrons.

Studies of dechanneling lengths in axially oriented crystals are, of course interesting; from a practical point of view as most of the electrons contributing to the radiation (for the positron sources) are quasi channeled we have not investigated this aspect.

## FROM BREMSSTRAHLUNG TO CHANNELING RADIATION:
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### 4- MOTIVATIONS FOR USING A CRYSTAL

‣ This idea started at LAL-Orsay in 1988. A group associated to a theoretician , Xavier Artru, from LPT-Orsay thought about the use of an atomic undulator using the strong fields of the atomic rows of a crystal , (instead of the alternating field of a magnetic undulator)  to generate the radiations from the electrons propagating at glancing angles from the rows.  The wavelengths crystal/magn.undulator are in a ratio $\sim\sim10^{-4}$ ➔ the needed e- energies $\sim\sim10^{-2}$ ➔ advantage   Also the crystal-radiator has smaller dimensions , mm, than the undulator, m)

‣ A preliminary study using Silicon and Germanium crystals in axial orientation to generate the photons and amorphous tungsten targets to create e-e+ pairs was presented at an accelerator conference (R.Chehab et al. in Proceedings of 1989 PAC, Chicago, March 1989)
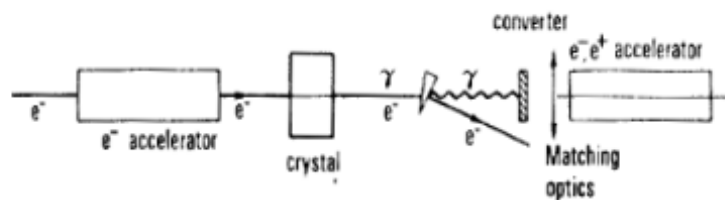
Figure 6 : Layout of a positron source using channeling

A positron accepted yield > 1 is obtained with 20 GeV incident beam on 1 cm crystal Ge/Si and 1 Xo for the converter
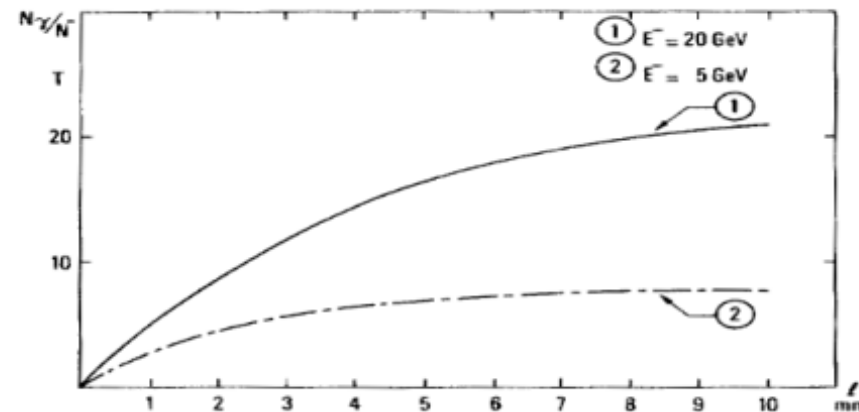This configuration is hybrid

Figure 3 : Cumulated number of photons generated by 5 and 20 GeV electrons in Germanium

① E⁻ = 20 GeV
② E⁻ = 5 GeV

γ simulations with FOT (X.A.); pair simulations with EGS

R.

# FROM BREMSSTRAHLUNG TO CHANNELING RADIATION: A PROMISING WAY FOR POSITRON GENERATION

▶ **Further developments**

▶ **After first simulations ➜ needs for deepening**

▶ **➜ Theoretical studies and simulations: X.Artru, V.N.Baier, VM.Katkov, V.M.Strakhovenko**

▶ **# simulation program (FOT from X.A.; see X.Artru, NIM B 48(1990)278-282 )**

▶ **# simulation program (SGC from V.M.Strakhovenko see V.N.Baier et al in NIMB 103(1995)and NIMB 15551999)403 )**

▶ **# Choice of W as crystal-radiator ➜ simulations (FOT) see X.Artru, V.N.Baier, R.Chehab, A.Jejcic in NIMA 344(1994)443**

▶ **➜ Proposition for a proof of principle experiment at LAL-Orsay {LAL, IPNL, IPNO, CdF, BINP)**



W crystal

Preshower & calorimeter
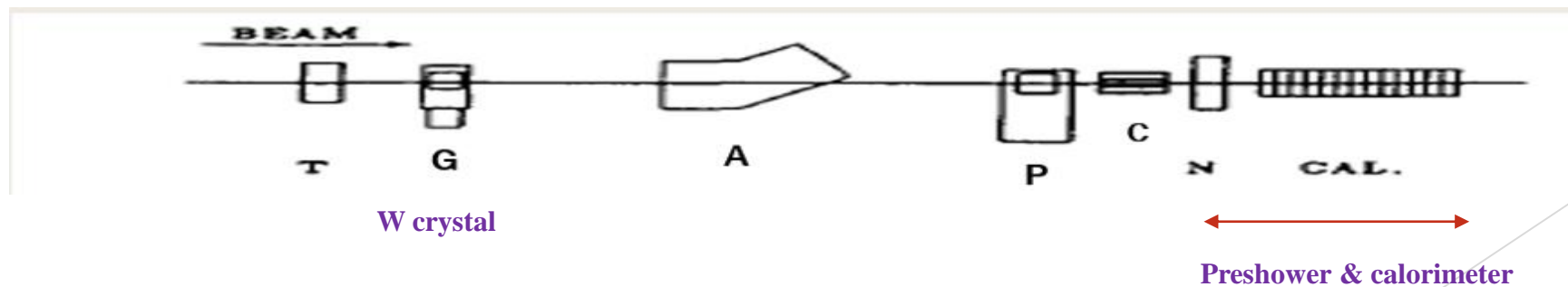
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**PROOF OF PRINCIPLE ➜ RESULTS**    **Experiment on 2 GeV linac at Orsay**

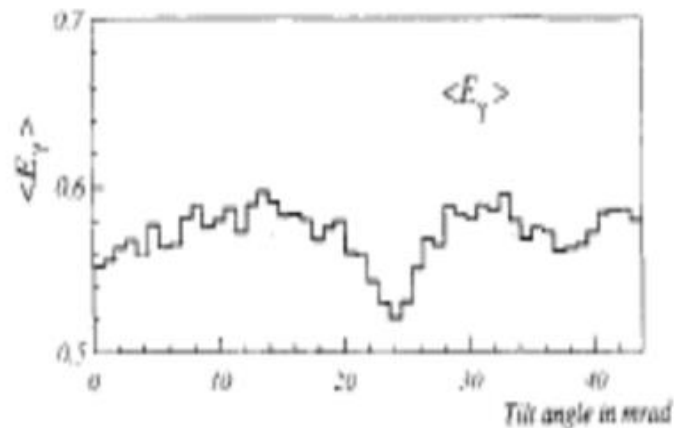**LAL-Orsay 1992-93**
**E⁻ ≤ 2 GeV; W crystal <111> orientation; 1 mm thick**



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 ver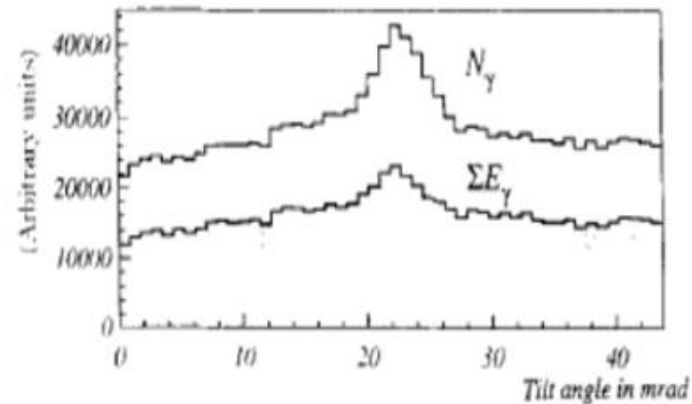tical one, the collimation angle is 1 mrad (from Ref. [14]). Both curves are represented in arbitrary units for the vertical scale.

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

See X.Artru et al. In Nucl.instrum.Methods B 119(1996)246-252

# FROM BREMSSTRAHLUNG TO CHANNELING RADIATION:
## A PROMISING WAY FOR POSITRON GENERATION

▶ **4-1-2 WHY PHOTONS FROM CHANNELING FOR FUTURE COLLIDERS ?**

▶ **\* <u>HIGH e+ YIELDS WITH HIGH γ YIELDS</u>: high photon yields are reachable with high Z crystals (high potentials) and GeV e- energies. Moreover, predominance of soft photons and then soft positrons more easily captured.**

▶ A comparison between a W crystal in

▶ axial channeling conditions and an

▶ amorphous target of the same thickness

▶ is showing the interest for axially

▶ oriented crystals. Here: W crystal with

▶ <111> orientation ( CLIC case: 1.4 mm

▶ thick): **simulation results ➔**



Crystal and amorphous targets of same thickness
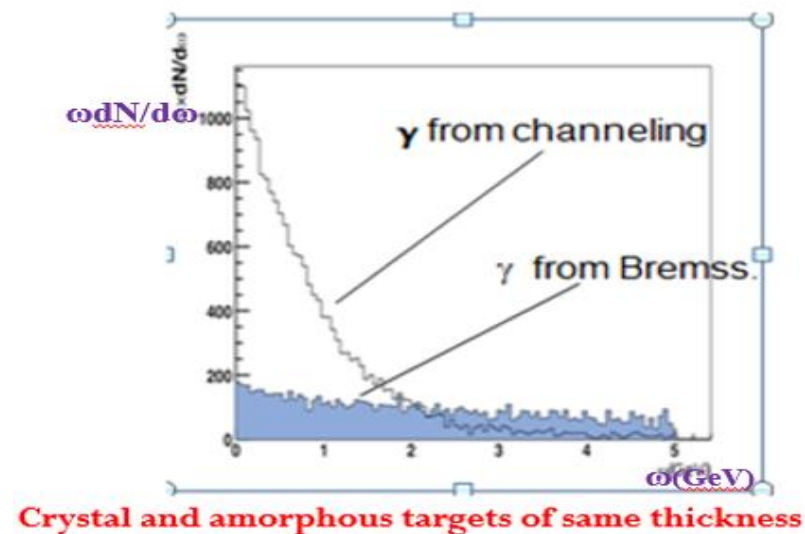
The vertical scale is in ω.dN/dω; as the bremsstrahlung has a law in 1/ω it is easier to see the difference.
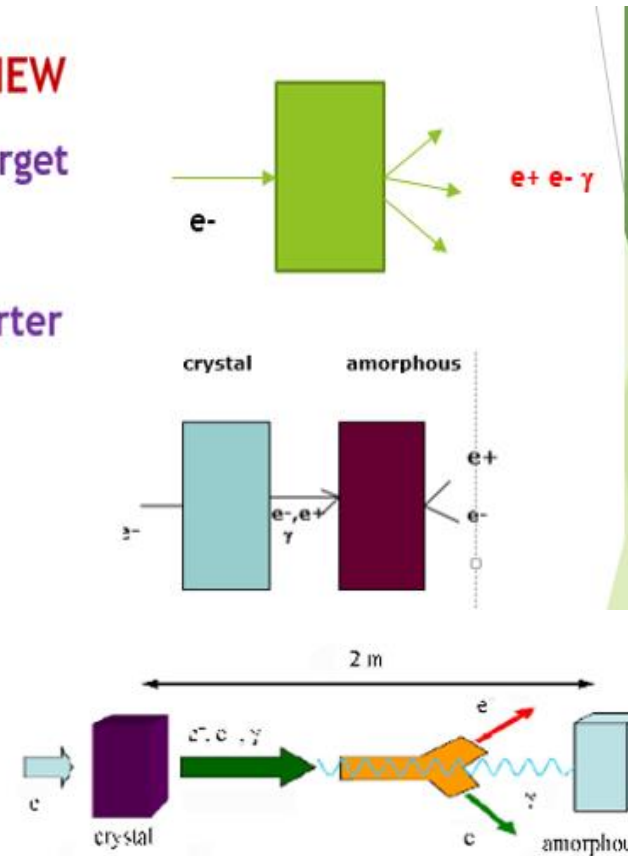
**FROM BREMSSTRAHLUNG TO CHANNELING RADIATION:**
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▶ **4-1-3 WHY PHOTONS FROM CHANNELING FOR FUTURE COLLIDERS ?**

▶ **\* HIGH PHOTON YIELD ➜ HIGH POSITRON YIELD WITH SOFT POSITRONS**

▶ **\* MODERATE INCIDENT ENERGIES (some GeV)**

▶ **\* CRYSTAL ALIGNMENT EASY WITH AVAILABLE PRECISE GONIOMETERS**

▶ **\* BUT WHAT ABOUT POLARIZATION?**

▶ **It is known that if both e+and e- beams are both longitudinally polarized there is: increase of the efficient polarization, easier identification of the new particles, reduction of the background (number of $W^+$, $W^-$ reduced)..**

▶ **Polarization of the positrons not so easy➜ the undulator option needs to construct the entire linac to get the polarized positrons; the Compton option needs very powerful lasers.**

▶ **Does the case of only polarized e- interesting? It appears that even with only polarized e- , the main background at IP comes from W pair production which can be reduced using polarized electrons right-handed as the coupling to W boson is left-handed. At 500 GeV the cross-section of W-pair production is 10 times less with polarized e- than with unpolarized e-** (see S. Yamashita in « Physics at ILC and role of polarized beams.)

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**4-2** ▶ **THE POSITRON SOURCE USING CHANNELING: A REVIEW**

▶ **# Thick crystals: radiation and conversion in the same target**

▶

▶ **# Hybrid: thin crystal-radiator & thick amorphous-converter**

▶

▶ **# Optimized Hybrid : decrease of the deposited energy**

**sweeping off the incident e- and the e+e- pairs from the crystal**



*Optimized hybrid scheme*

# FROM BREMSSTRAHLUNG TO CHANNELING RADIATION: A PROMISING WAY FOR POSITRON GENERATION

► **4-2-1 CRYSTAL CONVERTER**

► **\* For the incident electron energies considered (≤ 10 GeV) pair creation is well descibed by Bethe-Heitler formalism.**

► **\* The pair creation in strong fields is occuring at very small angles of photon incidence on the atomic strings and very high values of the photon energy and large crystal fields ($E_{phot}$ ≥ 14 GeV for W at 100 $^{o}$K )**

► **We restrict our presentation on the first case.**

► **Needs for high positron yields ➜ Large photon generation :**

► ➜ **\* Crystals with high potentials (high Z); W <111> axially oriented: U~1 kV at normal temperature)**

► **\* Thick crystal (enough shower development)**

► **\* High incident energy**

►

# FROM BREMSSTRAHLUNG TO CHANNELING RADIATION: A PROMISING WAY FOR POSITRON GENERATION

► **4-1-1 EXPERIMENTS WITH CRYSTAL CONVERTERS: WA 103 (CERN)**

**SPS TRANSFER LINES:** use of secondary electrons with $5 < E^- < 40$ GeV
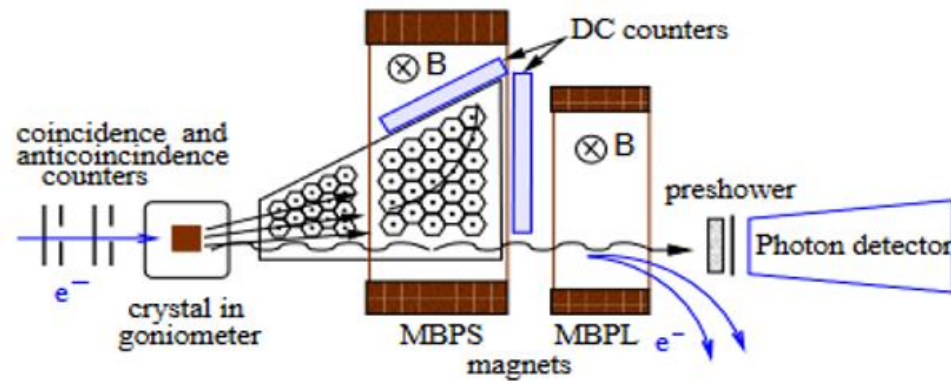


Figure 1: Experimental set-up

The angular acceptance in the horizontal plane was quite large: 30 degrees; the momentum acceptance for the positrons up to 150 MeV/c

The simulations associated to the experiment were done with V.M.Strakhovenko's code SGC

(see V.N.Baier, et al: Nucl.Instrum.Methods B, 103(1995)147 and 155(1999)403.

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▶ **4-2-1 RESULTS FROM WA 103**

**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)
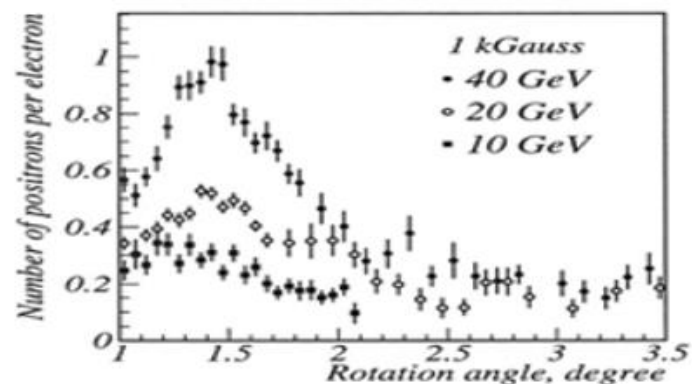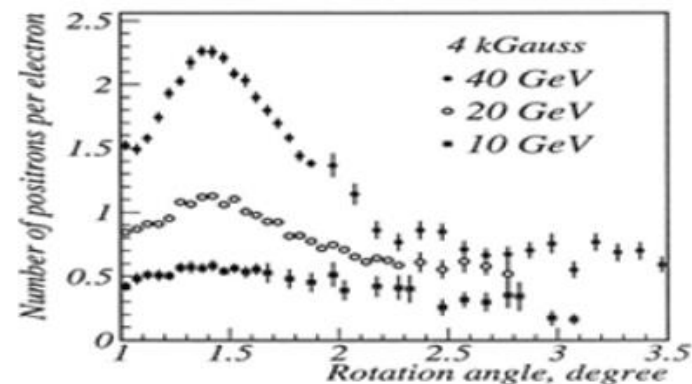


Figure 115: Rocking curves.

Figure 116: Rocking curves.

The positron yield is increasing with the incident electron energy; measurements on the side counters provide a simple and rapid way to observe the behaviour of the yield w.r.t. the e- energy

# FROM BREMSSTRAHLUNG TO CHANNELING RADIATION: A PROMISING WAY FOR POSITRON GENERATION

## 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. **Enhancements about a factor 4 in γ and e+ for 4 mm W crystal and 10 GeV**

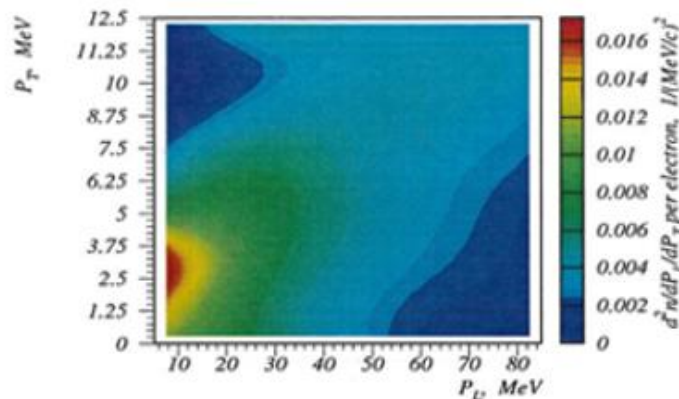### 12    Xtal 4 mm, 10 GeV

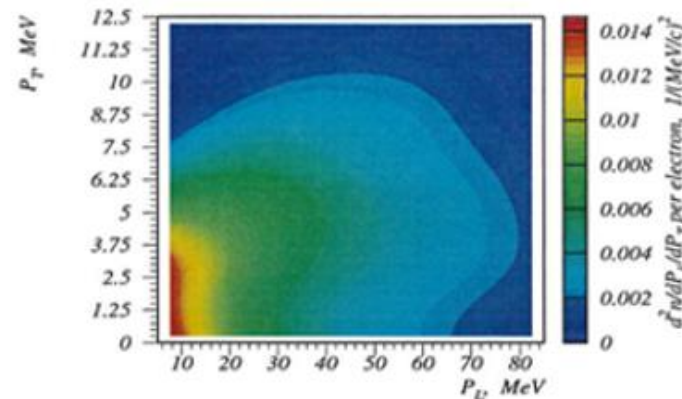### 12.1    Two dimensional map



Figure 119: Experimantal map

Figure 120: Calculated map

**WITH THE LARGE ANGULAR ACCEPTANCE OF THE DETECTOR, POSSIBILITY TO GET e+ PHASE SPACE POSITRON YIELDS➔ SIGNIFICANT: ABOUT 2.5 e+/e- FOR $P_T$ < 8 MeV/c AND  5< $P_L$ < 30 MeV/c (simulations and experiment)**

**Ref: R.Chehab et al. Phys.Letters B 525 (2002)41 and X.Artru et al: NIM B 240 (2005)762**

# FROM BREMSSTRAHLUNG TO CHANNELING RADIATION: A PROMISING WAY FOR POSITRON GENERATION

## 4-2-3 CRYSTAL CONVERTER: DRAWBACK ???

**Thick crystal ➔ heating ➔ consequences**

on the available potential which is decreasing due to

the thermal vibrations of the atoms ➔ efficiency decreases

in radiation and so on pair creation.

We may observe the effects of the temperature on the continuum

potentials of the <111> axis of a W crystal. The potentials are using

The expression given by V.N.Baier et al :

$U(x) = Vo\{ln[1 +1/(x+b)] - ln[1+1/(x_0 +b)] \}$

With $Vo=Ze^2/d = 430$ Volts for W <111>; x, the distance to the axis;

$b=2u_1^2 /a_s^2$ with $u_1$ as the thermal vibration amplitude, and $a_s$ the screening radius.

We can observe that the available potential is decreasing by 40 %

for a temperature increase of 500 degrees w.r.t normal temperature. Effects

on the yield depend on the actual parameters (E-, N-, target thickness).

Ref. X.Artru et al, Particle accelerators vol. 59 (1998)19-41
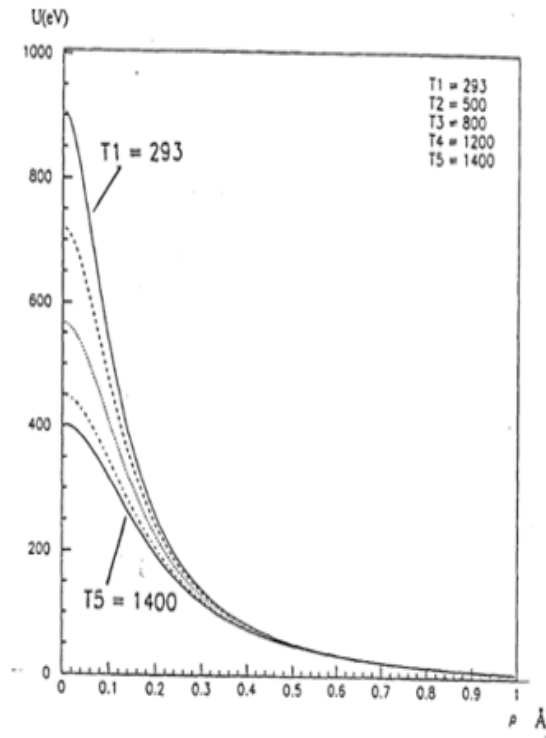
➔ **Towards an hybrid source?**



Figure 9 : Continuum potentials for the < 111 > axis of the tungsten crystal. The temperatures are expressed in ° Kelvin

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## 4-2-4  HYBRID POSITRON SOURCES TESTS AT KEK

- Assuming thin crystal target and, hence, moderate heating, in it and in order to lower the amount of energy deposited in the amorphous target and also the PEDD, the following scheme has been proposed
- [R.Chehab, V.M.Strakhovenko, A.Variola]

See X.Artru et al: NIMB 266(2008)3868
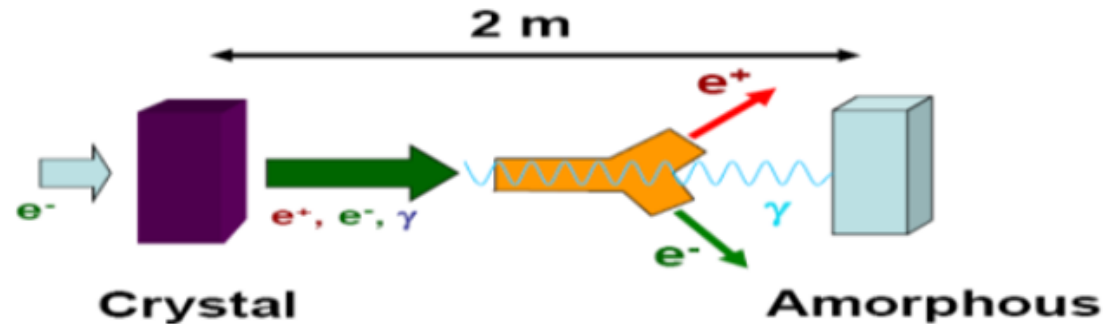


Putting a drift between the 2 targets allows sweeping off the charged particles coming from the crystal; only the γ impinge on the amorphous target

In the KEK lay-out the distance crystal-amorphous converter was about 3m.

# FROM BREMSSTRAHLUNG TO CHANNELING RADIATION: A PROMISING WAY FOR POSITRON GENERATION

**4-2-4-1** ▶ THE HYBRID POSITRON SOURCE ➔ KEK

▶ At KEK experiments with crystal converters and hybrid sources:

- 1- EXPERIMENTS WITH AN HYBRID SOURCE



amorphous    Drawing from Y.Uesugi et al. NIMB    319(2015)17
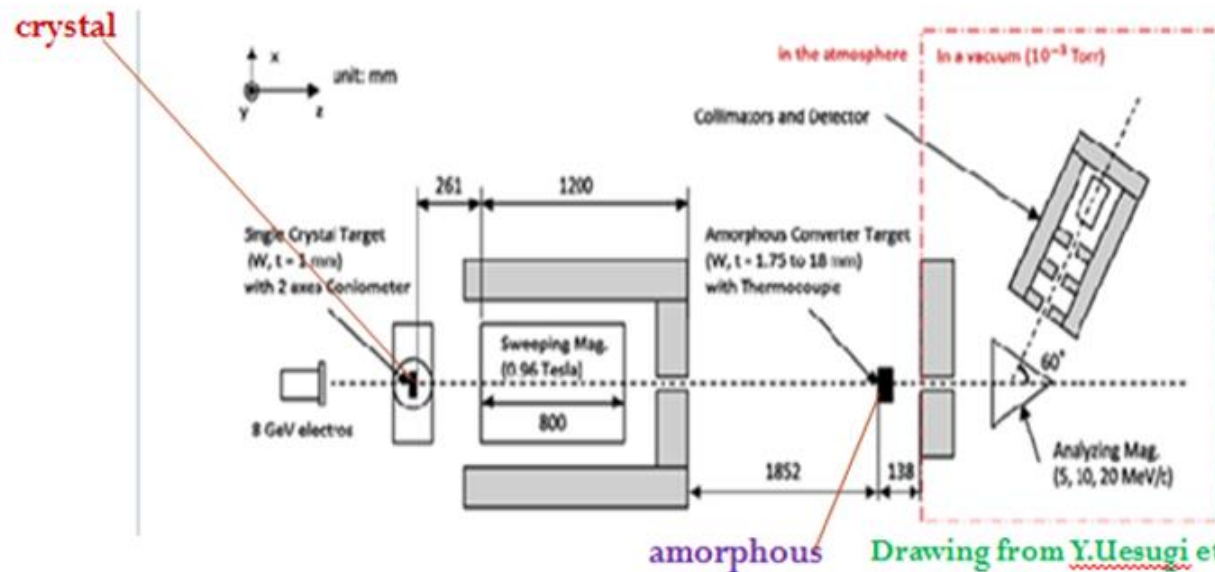
In this scheme only positrons are measured (not the photons); the angular acceptance of the detection system is very small.

R.CHEHAB/IJCLAB-PARIS-SACLAY/ AARP

# FROM BREMSSTRAHLUNG TO CHANNELING RADIATION: A PROMISING WAY FOR POSITRON GENERATION

**4-2-4-2** **TEST AT KEK WITH AN HYBRID SOURCE**

The positron yield has been measured in such configuration at different values of the positron momentum: 5, 10, 15 and 20 MeV/c. We represent, here, the results for P= 20 MeV/c

It is seen that the **on axis** hybrid scheme provides better yield than the conventional up to an overall thickness of 8 mm. The lower yield (w.r.t. conventional) at larger thickness is due to the larger angular spread for the hybrid target ( as shown by the simulations) associated to a low angular acceptance of the experimental positron lay-out
Y.Uesugi et al. NIMB 319(2014)17-23



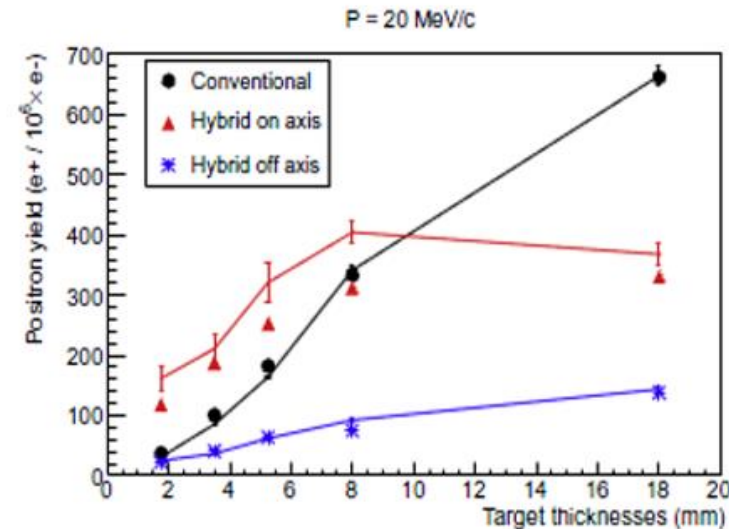A 1 mm W crystal <111> oriented and amorphous converters (W) of different thicknesses. Charged particles from crystal: swept off.
A conventional converter was also tested. .

# FROM BREMSSTRAHLUNG TO CHANNELING RADIATION: A PROMISING WAY FOR POSITRON GENERATION

▶ **4-2-1 EXPERIMENTS AT KEK**

▶ **Only « recently » photons were measured at KEK**

**TEST AT KEK OF HYBRID SOURCE (GRANULAR CONVERTER): october 2016**
Translation stage: Granular targets + Reference target (8 mm compact) + photon detector (Diamond)



**Details on the measurements with granular converters are in the talk:**
**Advantages of hybrid positron sources with granular converters**
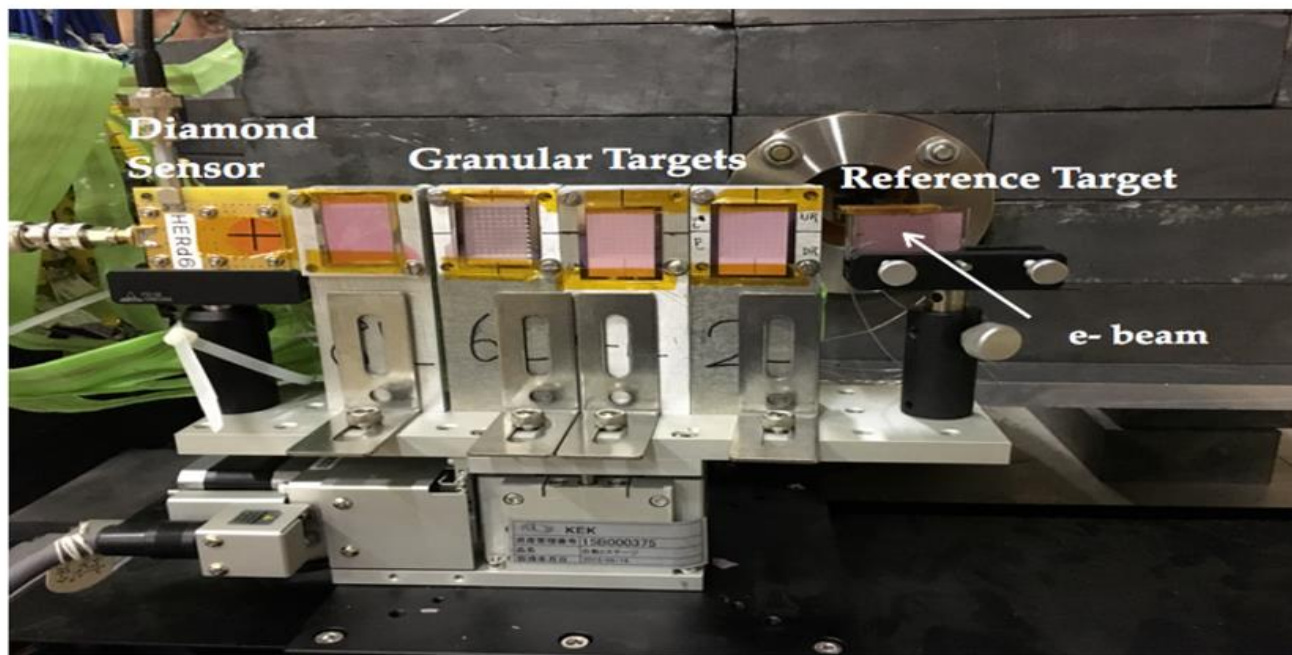
# FROM BREMSSTRAHLUNG TO CHANNELING RADIATION:
## A PROMISING WAY FOR POSITRON GENERATION

**TEST AT KEK: 2D SCAN FOR PHOTON DETECTION**

The crystal is W oriented on <111> axis; thickness 1 mm

A 2D scan (+/- 5.7º in $\theta_x$ and $\theta_y$ ) associated to the Diamond detector allowed observations of different channeling directions. The dimensions of the diamond detector were:

thickness: 500 μm; transverse dimensions 4x4 mm²

Three planes with maximum brillance are intersecting at 60 degrees around the <111> axis. Some axes have also been recognized. (with the help of a stereographic projection)
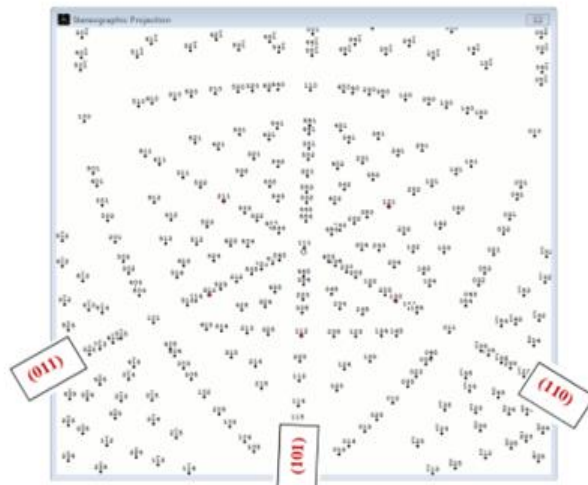


Figure B : stereographic projection for the W crystalaround<111> axis.Three planes containing<111> axis and at 60° one from the other are indicated.
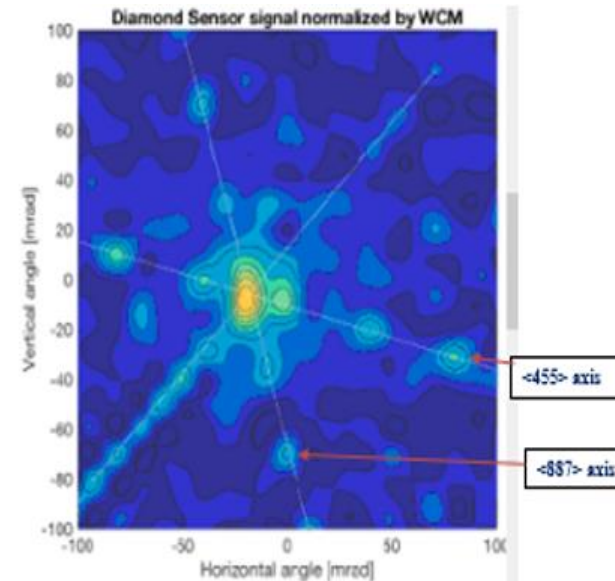


Angular steps of the goniometer: 1 mrad; This figure ➔ the cumulated data; corresponds to several minutes of data taking

This figure is a scan of the crystal orientation

Measurements at KEK by I.Chaikovska, V.Kubitsky et al. : see Proceedings of IPAC2017, Copenhagen

# FROM BREMSSTRAHLUNG TO CHANNELING RADIATION: A PROMISING WAY FOR POSITRON GENERATION

▶ **4-3-CHALLENGES FOR THE HYBRID SOURCE**

▶ **\* Radiation resistance for the crystal:** Beam incident fluence $\Phi < \Phi_{critical}$ for which atom dislodgements are occuring. Tests with W crystal at SLAC➜ no damages up to $2.10^{20}$ e-/cm$^2$

▶ **\* Heat load for the converter:**

▶ **The second target** (amorphous) being thick enough, it is expected a rather important energy deposition with two consequences:

▶        **\* Important heating ➜ needs of efficient cooling system**

▶        **\* as the energy deposited density is not uniform there are thermal and mechanical stresses which could lead to the target breakdown (see SLC target). It is then important to verify that the Peak Energy Distribution Density (PEDD ) does not overcome a certain limit. Following the SLC target analysis this limit was given as 35 J/g for a W target.**

▶ **Experiments at MAMI (Mainz) have been realized to study these two problems**

▶ Some details on heat load and target cooling are given in the next talk: « Advantages of hybrid positron sources with granular converter ».

# FROM BREMSSTRAHLUNG TO CHANNELING RADIATION: A PROMISING WAY FOR POSITRON GENERATION

▶ **COLLABORATIONS FROM THE BEGINNING UP TO NOW**

▶ The works on positron sources using channeling in crystals started at Orsay with LAL physicists (F.Richard, F.Couchot, R.Chehab) and X.Artru, at that time at LPT-Orsay. It was developped with the collaboration of IPN-Lyon channeling group (J.Remillieux), a theoretical group from BINP (V.Baier), a group from College de France (A.Jejcic) and a group from IPN-Orsay(E.Hourani) resulting to the proof of principle experiment on the 2.3 GeV electron linac at Orsay. Later on, looking for a positron source experiment at CERN, a group of experimental physics (S.Serednyakov) working on VEPP-2M at BINP joined the physicists already involved. An experiment (WA 103) has been worked out at CERN with the additional collaboration of TPU (A.Potylitsyn) and of KIPT. The Max-Institute of Stuttgart provided the W crystals and analysed their caracteristics. The test on radiation damages was performed at SLAC, thanks to the collaboration of S.Ecklund and J.Clendenin.

A collaboration with KEK started in 2001 with tests of different crystals providing photons/positrons. Such collaboration worked continously up to now involving many physicists of KEK with, sometimes, contribution from TPU. The collaborations associated to the positron sources based on channeling are more and more developing . Collaboration also with INFN-Ferrara, with associated physicists from Belarus, is now going on. The positron group studies at IJCLab is, now, led by Iryna Chaikovska and participates actively in these collaborations.

The support of the direction of the different laboratories (LAL-Orsay with M.Davier, J.Lefrancois, F.Richard, A.Stocchi ; IPN-Lyon with B.Ille, BINP with A.N.Skrinsky, KEK..) was essential. Also the presentation in special symposia as RREPS and CHANNELING gave many occasions to have fruitful discussions with many physicists (russian, ukrainian, armenian, japanese,..).

This slide is showing how such activity needs collaborations and how also the specialized symposia are helpful.

# FROM BREMSSTRAHLUNG TO CHANNELING RADIATION: A PROMISING WAY FOR POSITRON GENERATION

▶ **INCREASING INTEREST IN HYBRID SOURCES**

▶ **\* COLLABORATION WITH KEK**

▶ **Since 2001 a collaboration started with KEK physicists on experimental studies of positron sources using channeling. Crystal-converters as hybrid sources were installed in the test station having a 7-8 GeV electron beam. W, Si and C(d) crystal were used. Recently granular converters were used associated to W crystals. Many publications have described the obtained results.**

▶ **# T.Suwada et al. « Positron production experiment in tungsten crystal using 4-GeV and 8 GeV channeling electrons at the KEKB injector linac » in EPAC 2002 Proceedings, p. 509-511**

▶ **# T.Suwada et al. « Measurement of positron production efficiency from a tungsten monocrystalline target using 4 and 8 GeV electrons » in Phys.Rev.E 67(2003)016502**

▶ **« M.Satoh et al. « Experimental study of positron production from silicon and diamond crystals by 8 GeV channeling electrons » in NIM B 227(2005)3-10**

▶ **# T.Suwada et al. « Experimental study of positron production from a 2.55 mm thick silicon crystal target using 8 GeV electron beams with high bunch charges » in NIM B 252(2006)142-147**

▶ **# T.Suwada et al. « First application of a tungsten single crystal positron source at the KEK-B factory » in Phys.Rev.ST Accel.Beams 10(2007)073501**

▶ **#  X.Artru et al. « A positron source using channeling in crystals for linear colliders » in Int.J.Mod.Phys.A 25S1(2010)106-117**

▶ **#Y.Uesugi et al. « Development of  an intense positron source using crystal-amorphous hybrid target for linear colliders » in NIM B 319(2014)17-23**

▶ **# X.Artru et al. « Investigations  on an hybrid positron source with a granular converter » in NIM B 355(2015)60-64**

▶ **# I.Chaikovska  et al. « Experimental Activities on High Intensity Positron Sources Using Channeling" IPAC 2017 Proceedings**

▶ **The collaboration is going on (FCC-EE project, SuperKEKB positron source,..)**

# FROM BREMSSTRAHLUNG TO CHANNELING RADIATION: A PROMISING WAY FOR POSITRON GENERATION

**\* <u>COLLABORATION WITH INFN-FERRARA</u>**

▶   **A collaboration with INFN-Ferrara started and is being developped on simulations of positron hybrid sources and also on some tests worked out at MAMI.**

▶   **# Since some years mutual discussions on positron sources using channeling (L.Bandiera, A.Mazzolari et al) In Ferrara and Orsay**

▶   **# Stay of Mattia Soldani at IJCLab (PhD student from INFN-Ferrara) ➔ simulations on positron source based on hybrid scheme in the framework of FCC-ee project.**

▶   **# Common participation of Orsay, Ferrara and Mainz groups to tests at MAMI (tests of W crystals under high beam fluence; temperature measurements on the crystal and the converter)**

▶   **➔ A common article : L.Bandiera et al. « Crystal based positron source for a lepton collider positron source » in Eur.Phys.J.C. (2022)82:699**

# FROM BREMSSTRAHLUNG TO CHANNELING RADIATION: A PROMISING WAY FOR POSITRON GENERATION

▶ **STUDIES ON HYBRID SOURCES BY DIFFERENT GROUPS**

▶ # B.Azadegan et al. « Positron energy distributions from a hybrid positron source based on channeling radiation » in NIM B 309(2013)56; spectral-angular distributions of channeling radiation as pair conversion in an amorphous target are calculated for an hybrid source.

▶ # W.Wagner et al « Simulation of positron spectra of a hybrid positron source » in Journal of instrumentation, vol.15 (2020), RREPS-19. Axial (<100> ) channeling radiation in W and C(d) crystals is the source of photons for conversion in amorphous target. Radiation spectra are described.

▶ # S. Abdbrashitov et al. « Computer simulation of electron-positron pair production by channeling radiation in amorphous converter » in Journal of physics conference series 732(1):012021. The case of an hybrid source (W-crystal, W amorphous converter) with the 200 MeV incident e- beam. Axial channeling radiation providing photons for conversion. Positron yields are provided. See also S.B.Dabagov et al. « Hybrid positron-source scheme intended for the SPARC accelerator facility at the LNF » in Journal of surface investigation, X-ray, Synchrotron radiation and Neutron techniques vol.10 (2016)254.

▶ # S.Abdrashitov et al. «¨Positron source based on coherent bremsstrahlung of 10-50 MeV electrons » . S.V. Abdrashitov *et al* 2020 *JINST* 15 C10011. This work is considering the advantages of using the Coherent Bremsstrahlung instead of Channeling Radiation as the created photons have larger energies which could be reached with more moderate incident electron energies. The case of 10-50 MeV electrons is considered.

▶ # M.Shafeei et al. « Simulation of the hybrid positron source based on planar and axial channeling radiation of relativistic electrons » in Journal of research on many-body problems, vol.9, No 3, Athum 2019 145. Journal of research on many body systems , vol.9, No 3, Athumn 2019 145. Hybrid sources using channeling radiation in Si, Ge and W crystals

# FROM BREMSSTRAHLUNG TO CHANNELING RADIATION: A PROMISING WAY FOR POSITRON GENERATION

▶ **SUMMARY AND CONCLUSIONS**

▶ To reach the high luminosities required by e+e- colliders and to avoid the important heating in conventional positron sources, intense sources of photons are associated to amorphous converters. Among them, the channeling radiation in oriented crystals seems a very promising way. The scheme involving a thin crystal associated to a thicker amorphous converter, the so-called hybrid source has been studied and experimented in laboratories like CERN and KEK. The results has shown positron yields compatible with the requirements of e+e- colliders. Optimizations concerning the crystal-radiator and the amorphous converter are going on. Collider projects as CLIC have chosen this kind of source as the basic one. Though polarization is not considered for this kind of source, the needed incident electron energy is almost the same as for Compton backscattering based polarized positron sources. The substitution of a Compton backscattering installation to the hybrid source appears almost easily practicable, as an upgrade, to have polarized positrons: that is not the case when a conventional source is chosen before building the undulator solution for polarized positrons as the two incident electron energies differ by two orders of magnitude.

▶ The interest on hybrid positron sources using channeling radiation is meeting an increasing interest as it is considered for future collider projects and studied by more physics groups in different laboratories.

# FROM BREMSSTRAHLUNG TO CHANNELING RADIATION:
## A PROMISING WAY FOR POSITRON GENERATION

▶ **BACK UP SLIDES**

# FROM BREMSSTRAHLUNG TO CHANNELING RADIATION: A PROMISING WAY FOR POSITRON GENERATION

## 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.
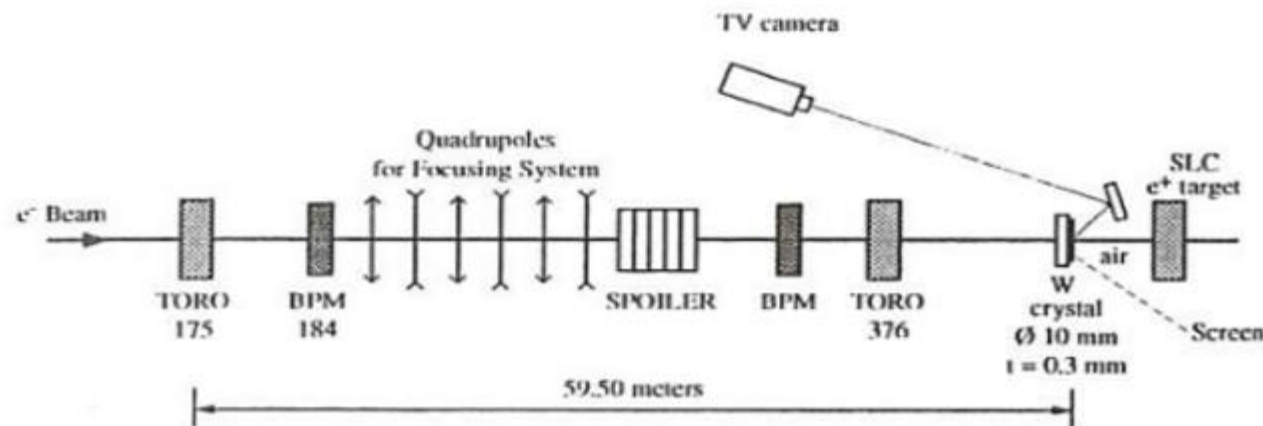


Figure 3: The SLC experimental set-up

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

# FROM BREMSSTRAHLUNG TO CHANNELING RADIATION: A PROMISING WAY FOR POSITRON GENERATION

## RESULTS OF THE TEST AT SLAC

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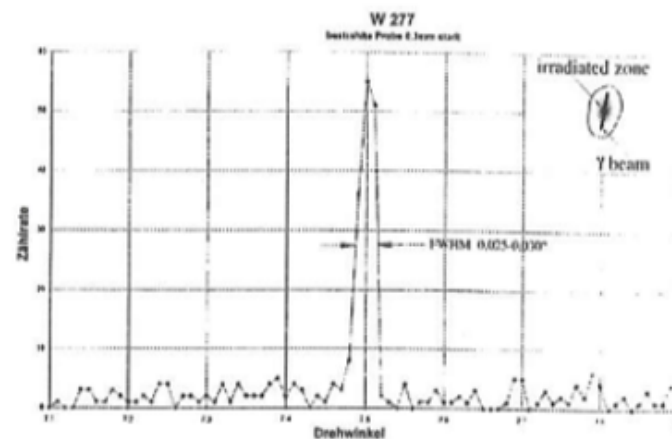


Figure 4: Mosaic distribution function of sample C2 obtained by γ-diffractometry. The γ beam is on the irradiated zone.