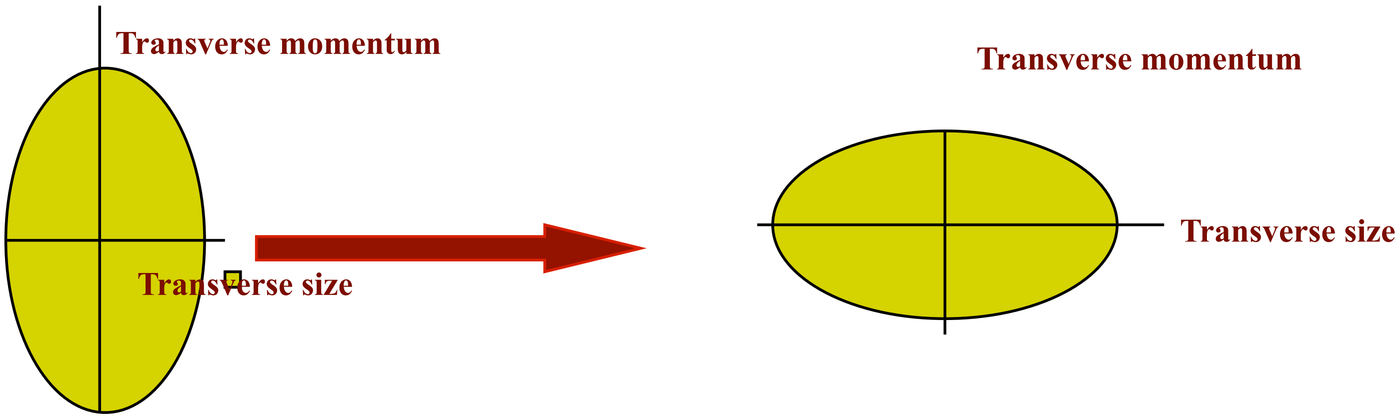
POSITRON SOURCES FOR e+e- COLLIDER: APPLICATION TO ILC AND CLIC

- SECOND PART:
- # CAPTURE AND ACCELERATION OF POSITRONS
- # RELIABILITY
- # SOME DEDICATED EXPERIMENTS

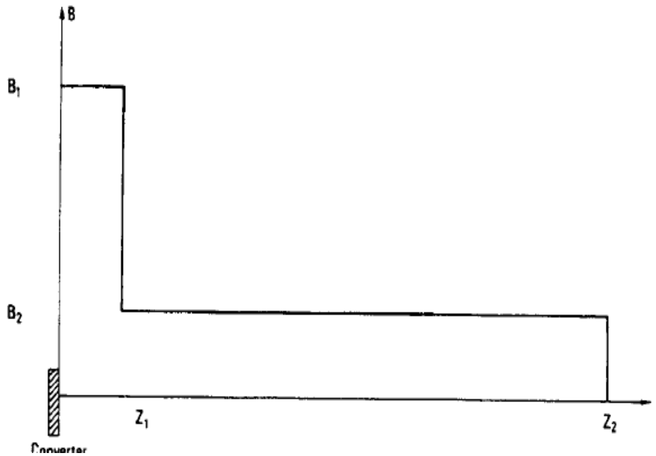
POSITRON SOURCES FOR e+e- COLLIDERS: APPLICATION TO ILC AND CLIC

- **2- CAPTURE AND ACCELERATION OF POSITRONS**
- **2-1 THE MATCHING SYSTEM**
- **The matching system (transverse phase space) transforms the e+ emittance at target output { large transverse momentum, small dimensions} in an emittance with different shape {small transverse momentum, large dimensions} easier to transport in the accelerator channel.**



POSITRON SOURCES FOR e+e- COLLIDERS: APPLICATION TO ILC AND CLIC

- 2-1 MATCHING SYSTEMS
- 2-1-1 AXIAL MAGNETIC FIELD SYSTEMS (SOLENOIDS)
- Two main kinds of solenoidal fields are used: the QWT (Quarter Wavelength Transformer) and the AMD (adiabatic Matching Device)
- 2-1-1-1 The QWT
- Made of a short lens with high magnetic
- field and a long solenoidal magnetic field.
- The emittance is rotated by π/2 in the
- phase space. This effect is due to
- the stepping field, introducing a
- B_r component.



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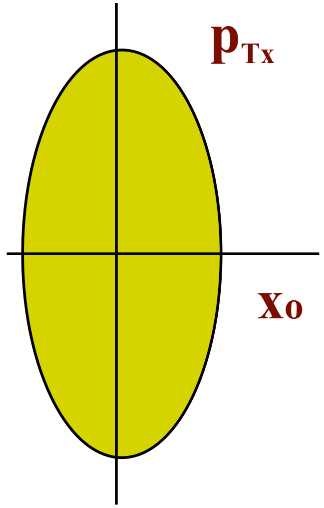
- MAIN FEATURES OF A QWT
- * Acceptance on the target plane
- The semi-axes are: $x_0 = (B_2/B_1)a$ and
- $p_T = eB_1 a[1+B_2/B_1]/2$; where B_1 and B_2 are the
- field values and a, the iris radius

  The target is inside the field
- * Momentum acceptance
- It is a <u>narrow band</u> system; typically,
- 3-4 MeV FWHM for B_1 = 2T and B_2 =0.3 T
- and an iris radius of ~1 cm



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- **2-1-1-2 ADIABATIC MATCHING DEVICE (AMD)**
- **This magnetic lens system has a magnetic field tapering slowly from a maximum value (B_o) to a minimum value (B_s) on a length L. From the maximum to the minimum values, the field varies adiabatically keeping constant the adiabatic invariant $\int\sum p_i dq_i = \pi p_T^2/eB$. Such system has a large momentum acceptance, provided the parameter of smallness $(P/eB^2)dB/dz$ be small enough (<<1).**

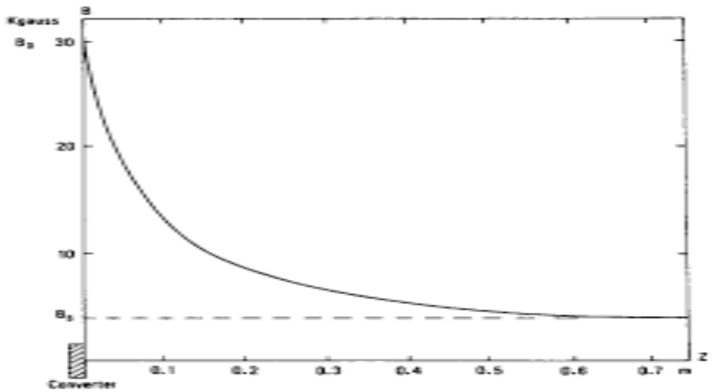
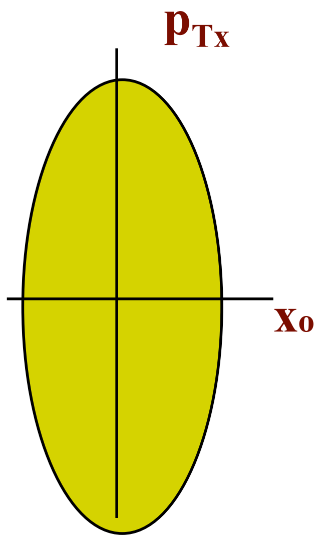


Fig. 17 Field profile of the adiabatic device

$B = B_o/(1 + \mu z)$

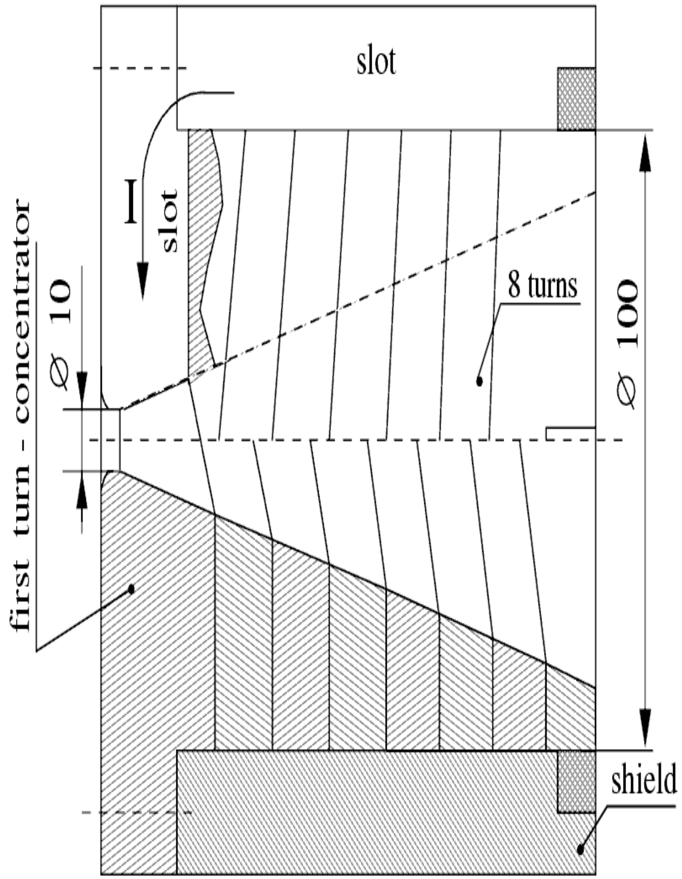
POSITRON SOURCES FOR e+e- COLLIDERS: APPLICATION TO ILC AND CLIC

- MAIN FEATURES OF THE AMD
- Acceptance on the target plane
- For a target *inside* the field, the
- Semi-axes are: $p_T = e[BoBs]^{1/2}.a$
- and $x_o = a.[B_s/B_o]^{1/2}$; a, iris radius
- Momentum acceptance
- It is rather large and limited on the
- higher part of the spectrum by the
- adiabatic constraint,
- $\varepsilon=(P/eB^2)dB/dz <<1$
- Typically ΔP ~20 MeV/c for
- B_o~5-6 Tesla and B_s~0.5 Tesla



POSITRON SOURCE FOR e+e- COLLIDERS: APPLICATION TO ILC AND CLIC

- **THE AMD**
- The device is using a Flux Concentrator
- It is a pulsed coil having a conical shape
- We represent a device studied at BINP
- The aperture at the target is rather small
- and enlarges after; typically, the initial
- aperture is of some mm diameter and
- the final of some cm. The field on the
- axis is inversely proportional to the
- cross-sectional area.



POSITRON SOURCES FOR e+e- COLLIDERS: APPLICATION TO ILC AND CLIC

- **2-1 MATCHING SYSTEMS**
- **2-1-2 AZIMUTHAL MAGNETIC FIELD SYTEMS**
- An azimuthal magnetic field created
- by a longitudinal current of radius Ro
- Circulating in the same direction of the
- Particles provides a strong focusing.
- The field is given by :
- $B = \{\mu_0 I / 2\pi R_0^2\} r$ for $r < R_0$
- $B = \{\mu_0 I / 2\pi r\}$ for $r > R_0$
- Such field focuses one of the particles
- and defocuses the other.
- 2 kinds of devices: Plasma lens
- and Lithium lens

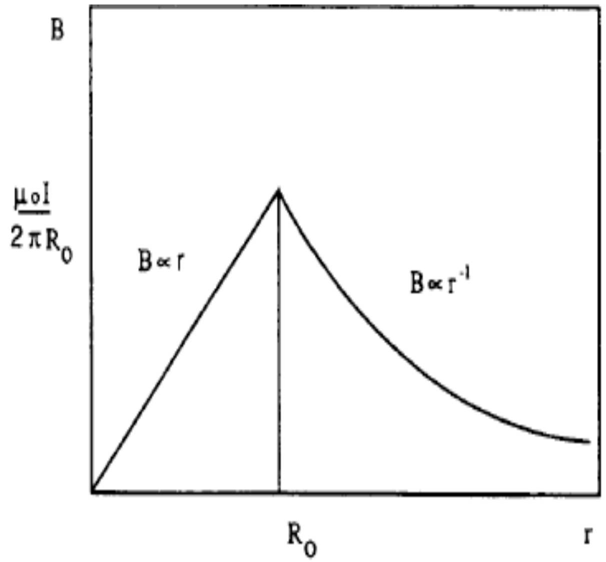


Fig. 19 Sketch of the azimuthal magnetic field

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- **AZIMUTHAL MAGNETIC FIELD: PLASMA LENS**
- **The conductor is a column of ionized gas.**
- **A high intensity pulsed current, created with a discharge circuit and flowing through the ionized gas (Argon) produces an imploding plasma column. The e+ moving through the plasma when the "pinch' is reached, are strongly focused .On the figure, the plasma lens {Brookhaven-Columbia}. Similar devices have been studied at CERN for antiproton focusing [B.Autin et al.]**

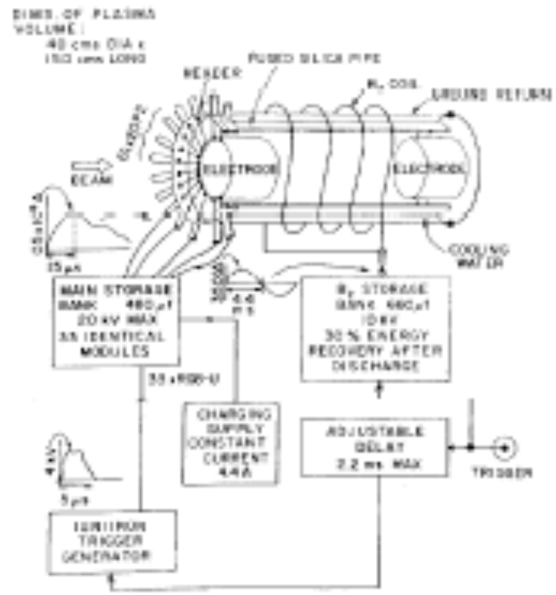

Fig. 1. System block diagram.

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- **AZIMUTHAL MAGNETIC FIELD: LITHIUM LENS**
- **The lens is made of a cylindrical**
- **lithium conductor traversed by a**
- **uniform current distribution. The**
- **Lithium is placed into a thin wall**
- **Titanium cylinder. First proposal**
- **was issued from BINP-Novosibirsk**
- **[G.Silvestrov]. A sketch of the lens**
- **proposed in 1997 is given. A variant**
- **With liquid lithium has also been**
- **Studied. The lens acts as a QWT.**

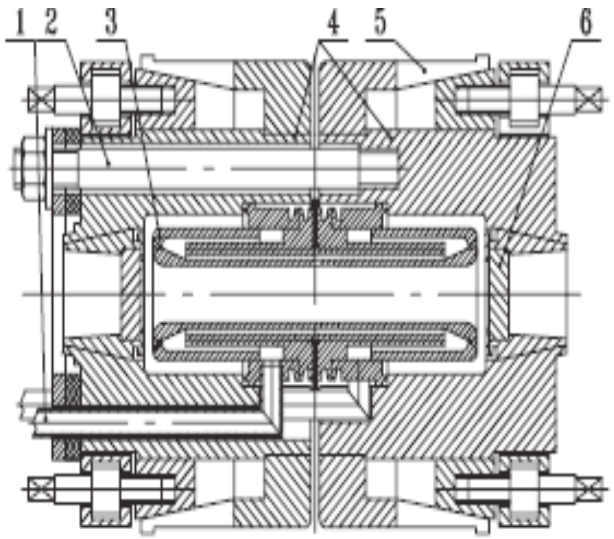


Fig. 1. BINP solid lithium lens with elastic shell.

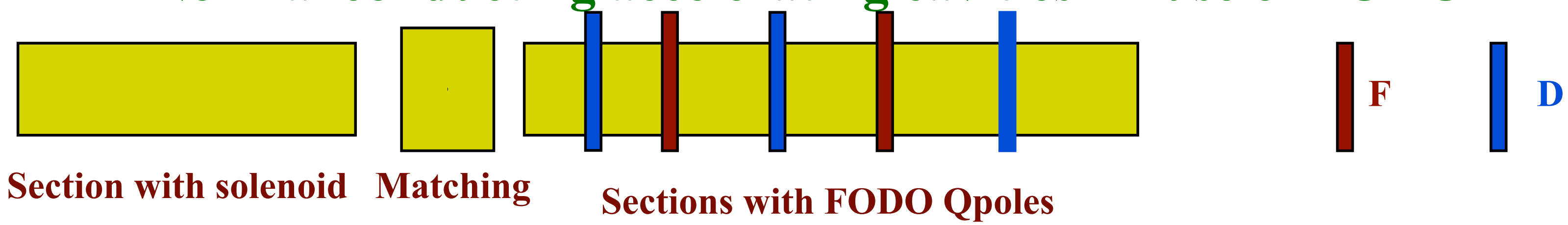
1 – water supply; 2 – retaining bolts; 3 – titanium body of the lens; 4 – steel body of the lens; 5 – collecting contact; 6 – beryllium windows.

POSITRON SOURCES FOR e+e- COLLIDERS: APPLICATION TO ILC AND CLIC

- 2-2 THE ACCELERATION
- The kind of acceleration just after the target is important:
- * for the longitudinal phase space: for bunch length and relative energy spread
- * for the transverse phase space: the accelerator iris aperture is an important element of the geometrical acceptance. Moreover, a strong accelerating field damp the beam divergence and, hence, the beam emittance.
- => in order to have a large acceptance, L-Band accelerating sections (with f_o= 1.3 Ghz) are preferred to S-Band sections (f_o=3 Ghz)

POSITRON SOURCES FOR e+e- COLLIDERS: APPLICATION TO ILC AND CLIC

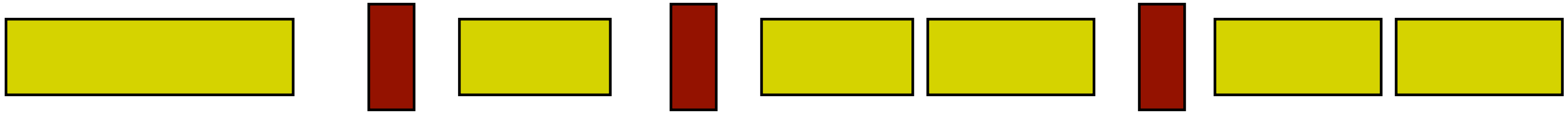
- **BEAM PHASE SPACE OPTIMIZATION**
- **The positron emittance being large, it must be reduced before injection in the main linac; that is the task of the Damping Ring. This injection requires a good matching to the DR acceptance. Two conditions:**
- **1/ Transverse emittance preservation; that means matching all along the accelerator prior to the DR. We can consider 2 cases:**
- *** Normal conducting accelerating cavities => use of FODO**



The matching device (doublet) transforms the circular beam shape into elliptical for a better transmission in the FODO system

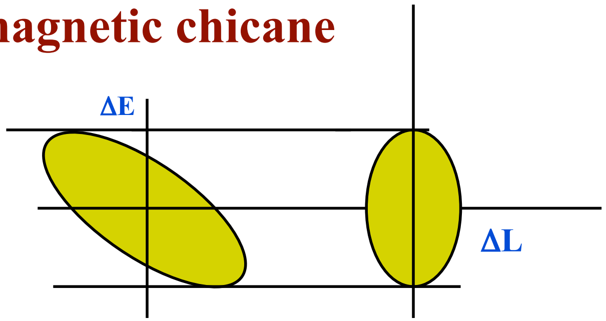
POSITRON SOURCES FOR e+e- COLLIDERS: APPLICATION TO ILC AND CLIC

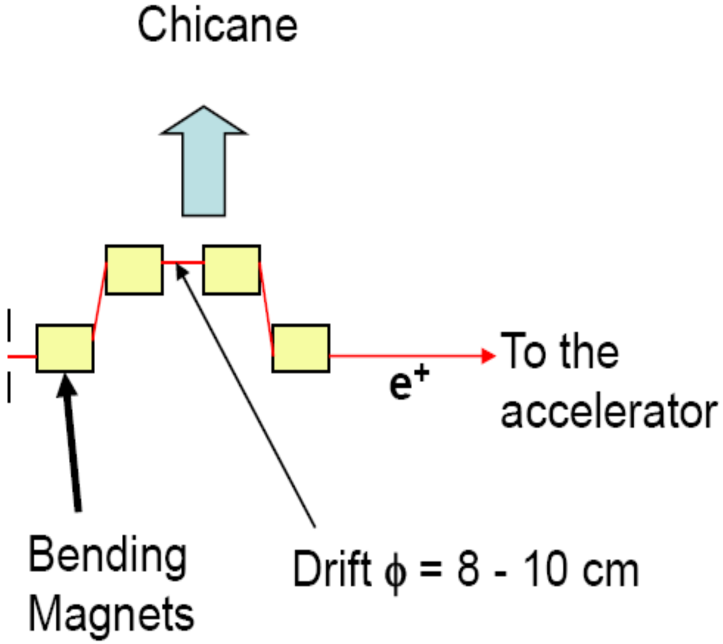
- * Superconducting cavities: use of triplet system between cavities



The triplets are put between the accelerating sections with an increasing geometrical periodicity, due to γ increase. Such system is well matched for ILC. If the section with solenoid is a normal temperature section, the other sections are superconducting.

POSITRON SOURCES FOR e+e- COLLIDERS: APPLICATION TO ILC AND CLIC

- **2/ Longitudinal phase space optimization**
- **Following the requirements for stacking in the Damping Ring, the positron longitudinal phase space may be transformed before injection in the DR.**
- **2-1/ Bunch compression: the bunch length may be reduced in a magnetic chicane**
- 



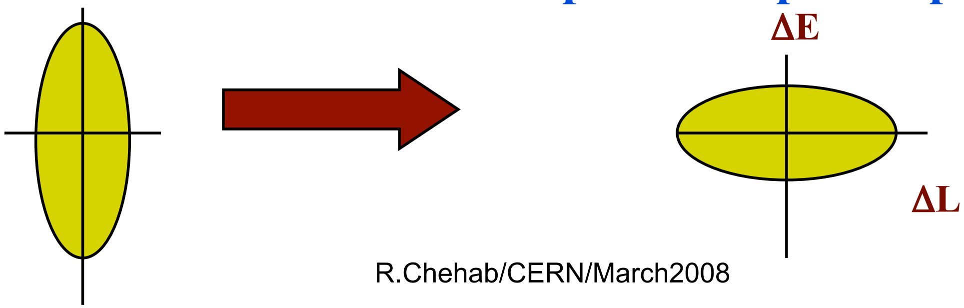
Bunch compression

POSITRON SOURCES FOR e+e- COLLIDERS: APPLICATION TO ILC AND CLIC

- **2-2/ Energy compression: many methods allow energy compression. As an illustration, we present that using an achromatic line associated to a debuncher. Schematically, the debuncher plays in the longitudinal phase space the same role as a lens in the transverse phase space with a "focusing"strength" α proportional to the electric field in the debuncher structure,**
-

$$M_D = \begin{vmatrix} 1 & 0 \\ -\alpha & 1 \end{vmatrix}$$

The global effect is to rotate the ellipse in the phase space



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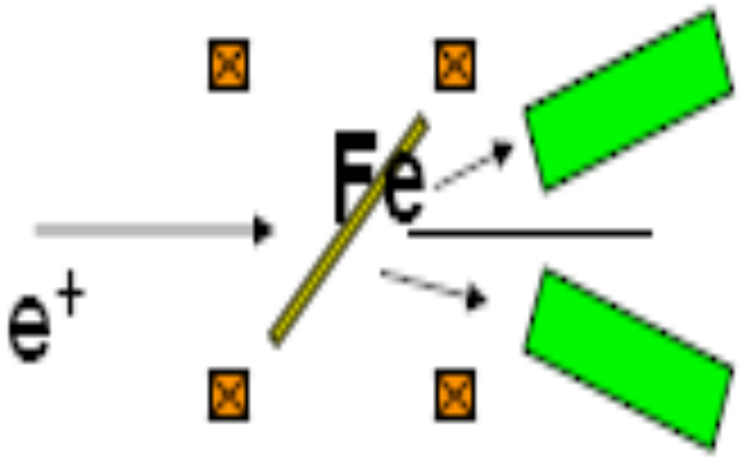
- **POLARIZATION CONTROL :** **the rate of longitudinal polarization of the positrons must be measured. One interesting possibility studied by S.Riemann et al (DESY-Zeuthen) is to do the measurement at relative low energy (200- 400 MeV) using Bhabha Scattering. The measurement of scattered e+ as well as of e- allows polarization determination. However, it would be more interesting to select the scattered e- to suppress the background due to bremsstrahlung**

Both e+ and e-(target) are polarized Pol(e-)~7% in Fe. Angular distribution of scattered e- , depending on polarization, is measured for two magnetization states of the target; asymmetry is of some %. For P^{+}=0.6 and P^{-}=0.07, maximum asymmetry is ~0.03. The needed angular aperture is < 10 degrees, for E+=400 MeV.



From LEPOL collaboration

POSITRON SOURCES FOR e+e- COLLIDERS: APPLICATION TO ILC AND CLIC

- **3- RELIABILITY**
- **The reliability of positron targets is depending mainly on:**
- **# the Peak Energy Density Deposition (PEDD)**
- **# the average temperature**
- **# the radiation resistance**

POSITRON SOURCES FOR e+e- COLLIDERS: APPLICATION TO ILC AND CLIC

- **3-1/ RELIABILITY: PEDD**
- **The local and almost instantaneous energy deposition in a target (for instance during a pulse duration) may be very critical for the target survival. Indeed, due to inhomogeneous energy deposition in the target, thermal gradients causing mechanical stresses lead to target destruction as by shock waves. After the SLC target destruction, analyses showed that a maximum value of 35J/g (in tungsten) must not be exceeded. So, an accurate simulation of the energy deposited in the target has to be worked out dividing the target in elementary domains (typically, disks with radius increments of tenths of mm and thickness of tenths of Xo). The energy deposited in each domain is calculated and comparisons made with the maximum allowed value. The PEDD is strongly depending on the incident beam intensity and on its transverse dimensions.**

POSITRON SOURCES FOR e+e- COLLIDERS: APPLICATION TO ILC AND CLIC

- **3-2/RELIABILITY: STEADY STATE TEMPERATURE**
- **In order to limit the average thermal heating of the target, efficient cooling and also rotating targets are considered. Limitation of the number of incident electron pulses on the same target is made easier including many targets on a rotating wheel. The constraints are somewhat stringent due to the fact that the wheel motion is in vacuum and that Eddy currents (associated to the strong magnetic fields of the matching lens) are appearing on the target. A limitation of the total energy deposited in the target may be of interest and as an example, the use of crystal targets is interesting (due to less energy deposition w.r.t. the amorphous targets, for the same yield) [See X.Artru et al PRST-AB 6 (2003)091003]**

POSITRON SOURCES FOR e+e- COLLIDERS: APPLICATION TO ILC AND CLIC

- **3-3/RELIABILITY: RADIATION RESISTANCE**
- **We shall consider the case of crystal targets where the elastic Coulomb collisions of the incident electrons on the aligned nuclei may dislodge the nucleus from the lattice. This dislodgement may occur if the recoil energy is above some threshold (E_d ~25 eV, for W). For a recoil energy larger than $2E_d$ the primary nucleus may initiate a cascade of displacements among the neighbouring atoms. An evaluation [See X.Artru et al. NIMA 344 (1994)443] showed that for W, a maximum fluence – accumulated number of incident particles per unit area- of 10^{20}e-/cm^2 is tolerable. An experimental test has been operated at SLAC (see below); this test was probably the first using electrons to test the radiation resistance of a crystal. Tests made with protons on Si showed no damages for the same fluence. We must note that annealing can occur during beam operation and as a consequence, the maximum fluence considered may be pessimistic.**

POSITRON SOURCES FOR e+e- COLLIDERS: APPLICATION TO ILC AND CLIC

- 4- SOME DEDICATED POSITRON EXPERIMENTS
- Since the introduction of positron sources in accelerators, many experiments devoted to their characteristics measurement were operated. We shall present some recent (in the last decade) experiments concerning polarized and unpolarized sources.
- 4-1 Experiments on crystal targets (unpolarized)
- # LAL test for a proof of principle of crystal source [on the 2 GeV linac]: simple mention
- # CERN experiment: WA 103
- # KEK experiment
- # SLAC experiment
- 4-2 Experiment with polarized beam
- # E-166 (SLAC)
- # KEK (some tests have been operated by T.Omori et al for a proof of principle of the Compton backscattered option): promising results were obtained [on ATF extraction line]: simple mention

POSITRON SOURCES FOR e+e- COLLIDERS: APPLICATION TO ILC AND CLIC

- **4-1-1/ WA 103 Experiment {On X5 transfer line of SPS}**
- **The experiment was dedicated to the measurement of the yield, energy spectrum and emittance of a positron source using channeling radiation in a tungsten crystal. In that experiment, secondary electron beams of the CERN SPS were impinging on W crystals (4 and 8 mm thick) oriented on their <111> axis and also on an amorphous W target (20 mm thick). Electron energies were between 5 and 40 GeV; most of the measurements were concerning 6 and 10 GeV incident energies. Particles coming out from the crystal/amorphous targets were detected in a drift chamber partially immersed in a magnetic field. The reconstruction of the particle trajectories provided the energy and angular spectra in a rather wide energy range [up to 150 Mev] and angular domain [30 degrees].**

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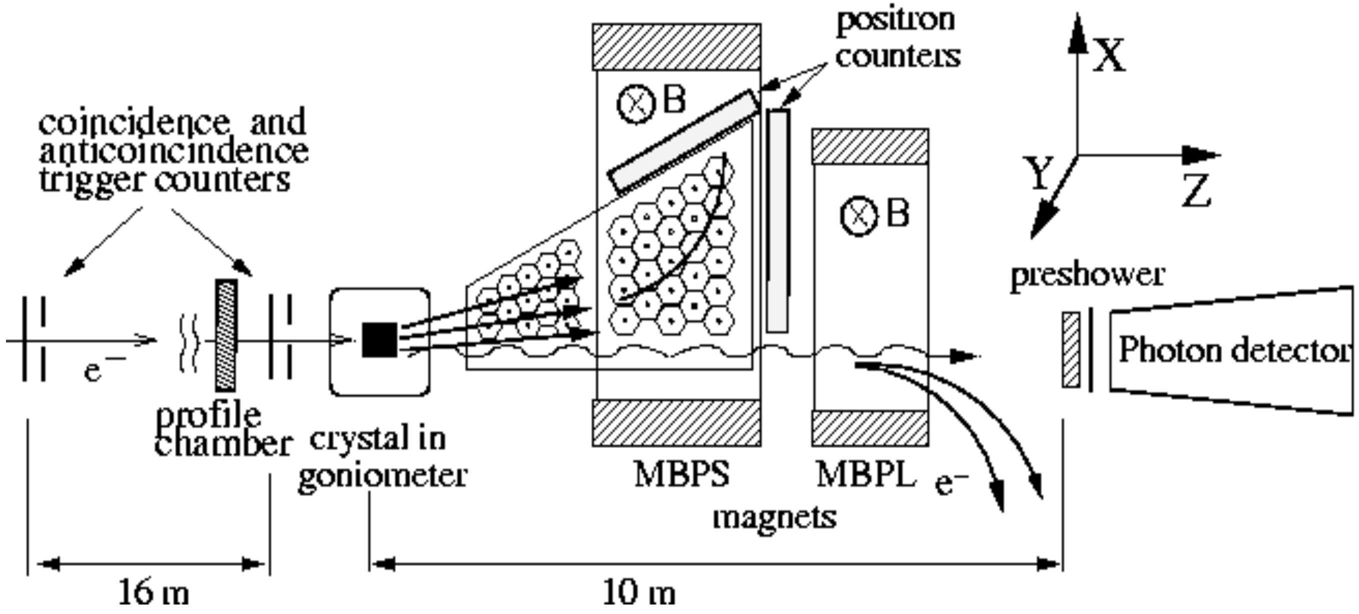
- **The WA 103 set-up**



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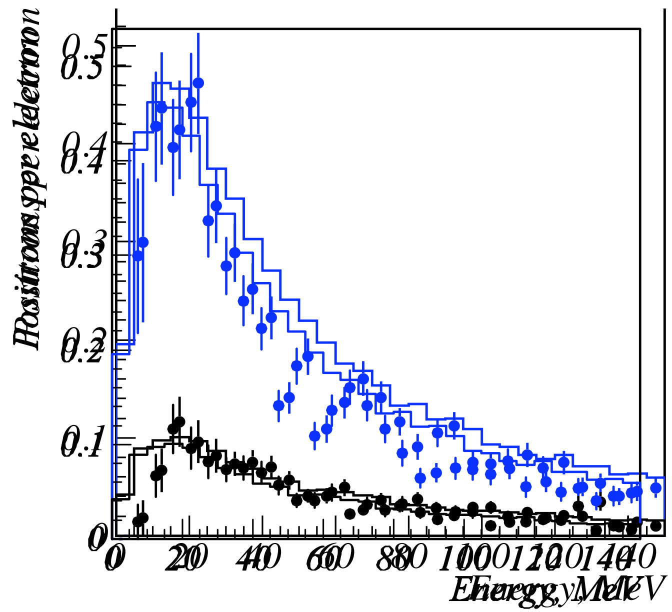
- The WA 103 results
- * Enhancement in e+ production
- In channeling conditions, the γ
- Production is enhanced and, hence,
- the positron generation. Comparison
- with amorphous target of same
- thickness showed more than a factor
- 4 of enhancement in the case of a 4 mm
- target at 10 GeV incident energy.
- [In blue, the 4 mm crystal; in black,
- the 4 mm amorphous]



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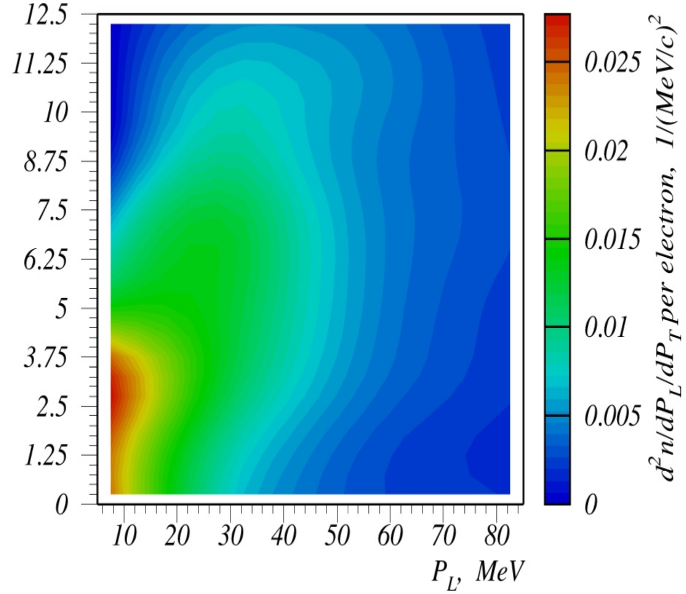
- **The WA 103: results on phase space**
- **The emitted positrons measured**
- **through trajectory reconstruction**
- **in the drift chamber are represented**
- **in the plane of longitudinal and**
- **transverse momenta $\{p_L, p_T\}$.**
- **We can see that the highest**
- **density of the positrons**
- **is situated in a domain $\{p_L<20$ MeV/c;**
- **$p_T< 5$MeV/c}; this is the case for a**
- **8 mm crystal submitted to 10 GeV e-**



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- **THE WA 103 RESULTS:** **Comparison experiment/simulation**

The crystal

experiment	$5 < p_L < 25$ MeV/c	$5 < p_L < 30$ MeV/c	$5 < p_L < 40$ MeV/c
$p_T < 4$ 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	$5 < p_L < 25$ MeV/c	$5 < p_L < 30$ MeV/c	$5 < p_L < 40$ MeV/c
$p_T < 4$ 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

TABLE I: Positron yield: 8mm crystal/10 GeV incident energy. Domains defined in longitudinal p_L and transverse p_T momenta.

Analogous results have been obtained for 5.7 Xo thick amorphous W target Submitted to 6 and 10 GeV electrons. See NIM B 240 (2005) 762-776

POSITRON SOURCES FOR e+e- COLLIDER: APPLICATION TO ILC AND CLIC

- **4-1-2 KEK experiment**
- **Many tests using W, Si and C(d) crystals have been operated on KEKB electron linac with incident energies of 4 and 8 GeV. Only the positrons were measured. The enhancement in positron production for aligned crystals has been measured for various configurations associating amorphous targets of different thicknesses, put after the crystal.**
- **Comparisons with CERN results**
- **Though using very different positron acceptance for the positron detection (much large for CERN, quite small for KEK) the values of enhancements crystal/amorphous could be compared [see V.N.Baier, V.M.Strakhovenko, PRST-AB 5 (2002)121001] and this comparison showed rather good agreement, for the same conditions.**

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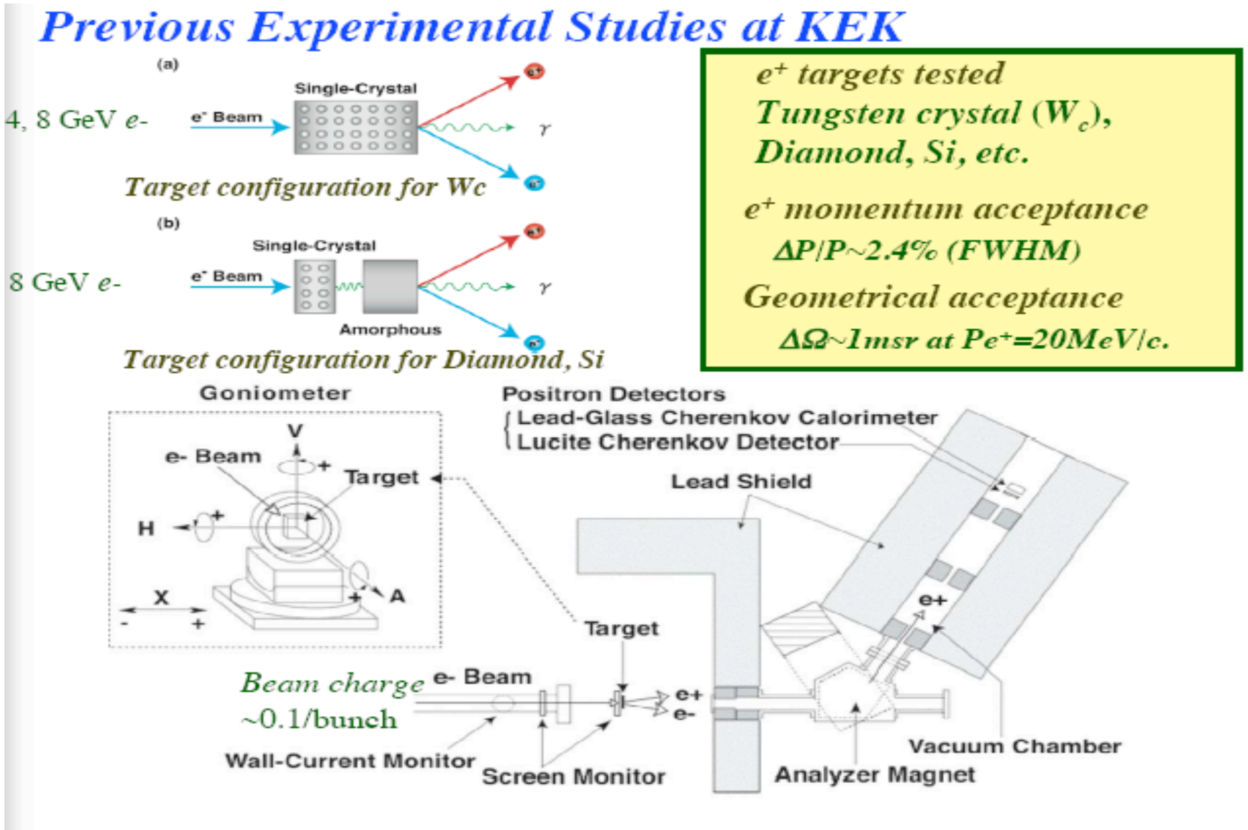
- The KEK set-up (from T.Suwada, seminar at KEK in 2007)

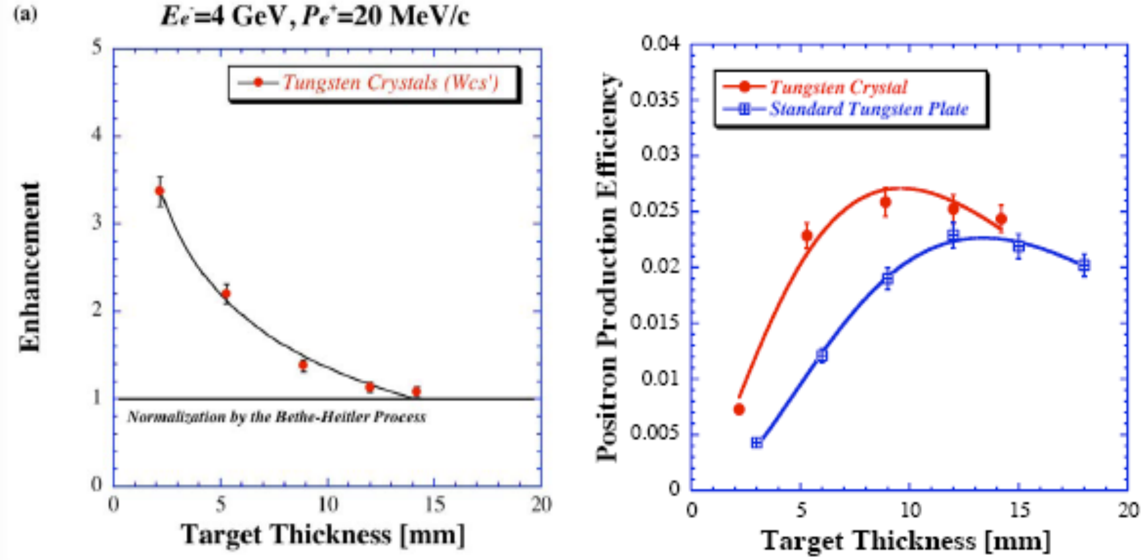


POSITRON SOURCES FOR e+e- COLLIDERS: APPLICATION TO ILC AND CLIC

- **KEK tests results** **(from T.Suwada); results at 4 GeV incident energy**

Previous Experimental Results:

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



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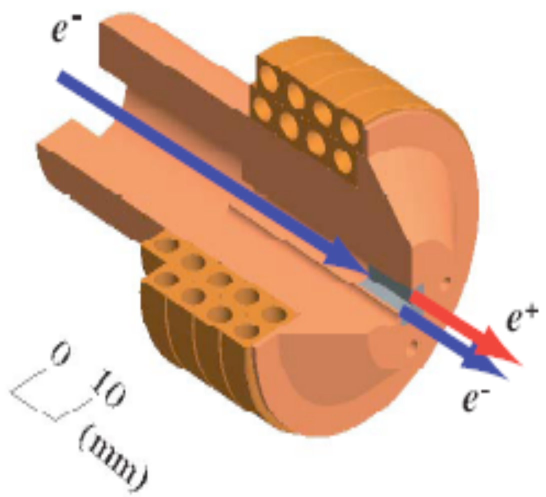
- **Following the successful tests on KEKB linac, a W crystal target (10.5 mm thick) was put at the KEKB linac at positron source location.**
- **The crystal was embedded in a copper cylinder and accurate prealignement was carried out in order to avoid the use of a goniometer.**

The central axis of the cylindrical copper body corresponded exactly to the <111> crystal axis



Results: as foreseen, the e+ yield improvement was 25% with respect to the former amorphous target and remains stable since july 2006. The incident e- beam is 7.7nC/bunch at 4 GeV.

POSITRON SOURCES FOR e+e- COLLIDERS: APPLICATION TO ILC AND CLIC

- **4-1-3 The Radiation Resistance SLAC experiment [1995-96]**
- **A Radiation Resistance test on a 0.3 mm thick tungsten crystal has been operated at SLAC. The crystal was installed before the SLC target and submitted to the 30 GeV incident e- beam during 6 months. The average intensity was 2.5×10^{10} e-/pulse with 10, 30 and 100 Hz successively. Incident beam intensity, spot dimensions and position were monitored. At the end of the irradiation the integrated intensity was 1.2×10^{19}e-. The integrated total flux (fluence) experienced by the crystal reached 2×10^{18}e-/mm^2. Before and after the irradiation, the mosaic spread has been measured at the Max-Planck Institute of Stuttgart using a γ-diffractometry method.**

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- **The SLAC Radiation Resistance Experiment Set-Up**

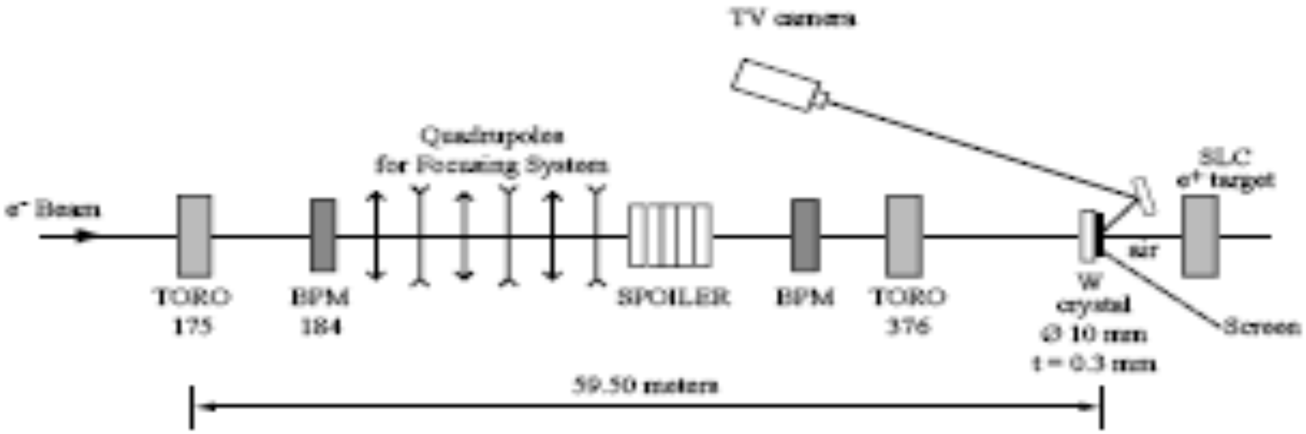


Figure 3: The SLC experimental set-up

POSITRON SOURCES FOR e+e- COLLIDERS: APPLICATION TO ILC AND CLIC

- **THE RADIATION RESISTANCE EXPERIMENT: RESULTS**

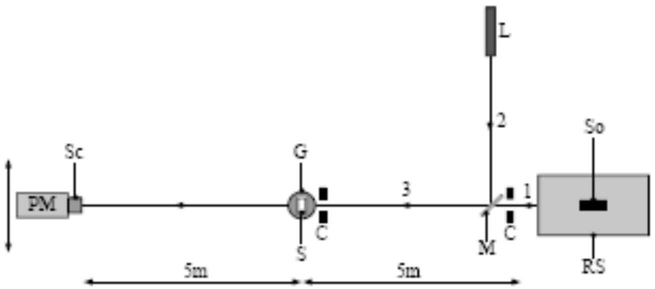


Figure 2: The Stuttgart γ -diffractometer set-up. So: ^{137}Cs radioactive source, RS: radiation shield, C: collimators, L: laser light source, M: mirror, G: goniometer, S: sample, Sc: BGO scintillator, PM: photomultiplier, 1: γ beam, 2: laser light, 3: γ beam and laser light.

The MPI analysis set-up

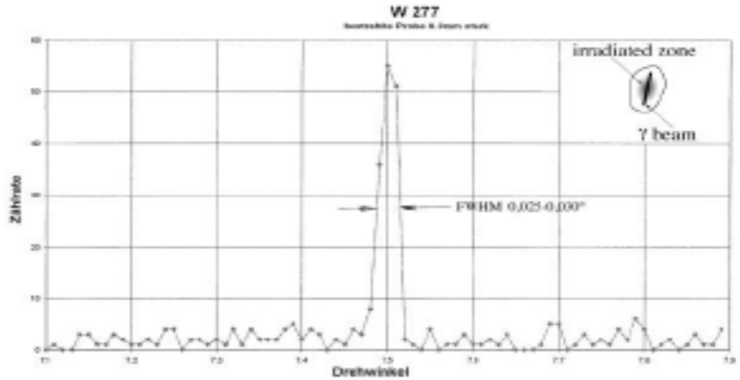


Figure 4: Mosaic distribution function of sample C2 obtained by γ-diffractometry. The γ beam is on the irradiated zone.

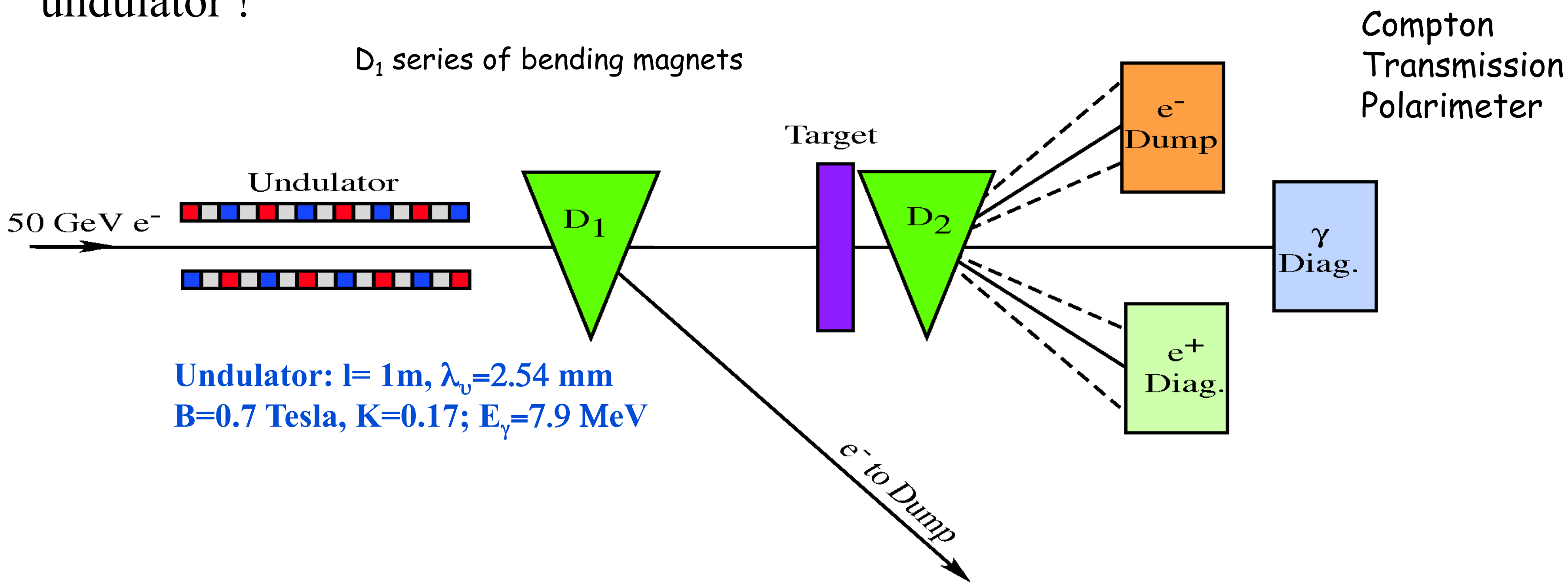
The crystal rocking curve

The compared mosaic spreads –FWHM widths of rocking curves- showed no differences before and after irradiation=> no damages

POSITRON SOURCES FOR e+e- COLLIDERS: APPLICATION TO ILC AND CLIC

- **4-2 The E-166 experiment [SLAC]** **From R.Dollan**

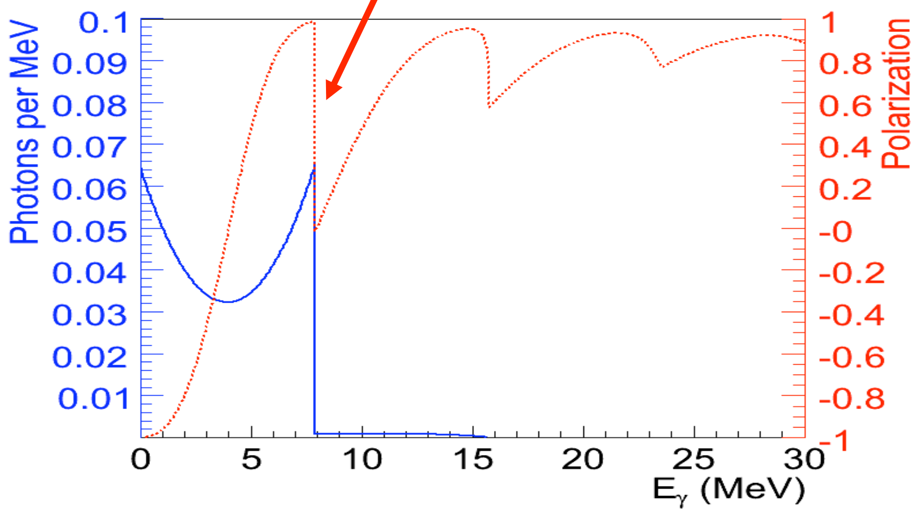
Task: proof the possibility, to produce polarized positrons using a helical undulator !

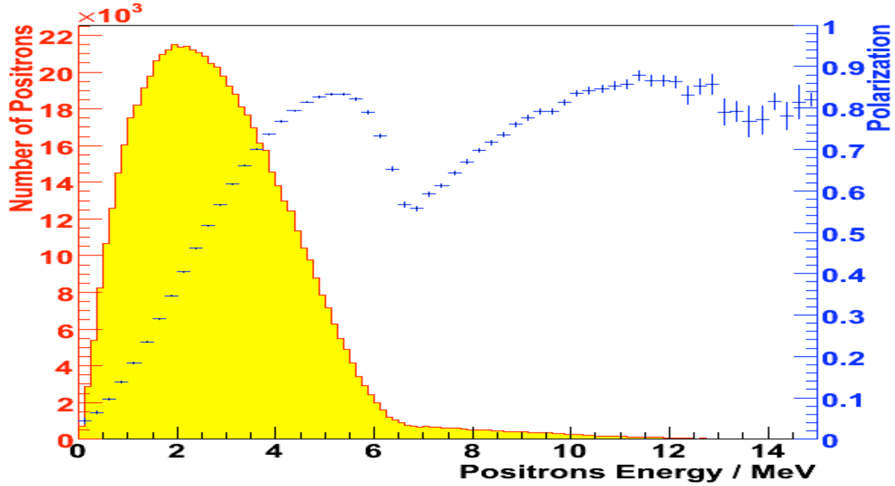


POSITRON SOURCES FOR e+e- COLLIDERS: APPLICATION TO ILC AND CLIC

- **E-166: PHOTON AND AND POSITRON SPECTRA (from R.Dollan)**

E_{cutoff} (1st harmonic) : 7.89 MeV





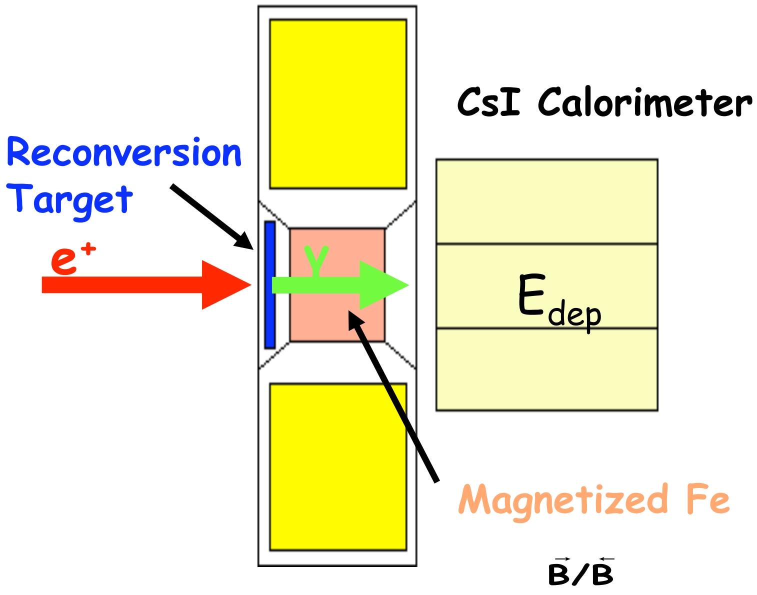
Undulator photon spectrum
K=0.17; E-= 46.6 GeV

expected positron spectrum generated in a 0.5 X_0 W target

POSITRON SOURCES FOR e+e- COLLIDERS: APPLICATION TO ILC AND CLIC

- E-166 EXPERIMENT: Polarization measurement (from R.Dollan)

Compton Transmission Polarimeter
{Method tested successfully at KEK}
Reconversion of longit. Polarized e+ to circularly polarized γ
The γ traverse magnetized Fe
Polarization dependent transmission
determination of asymmetries for 2 opposite Fe polarization states



Asymmetry: $\delta \sim nLP_{e-}P_{\gamma}\sigma_{pol}$, with $P_e \sim 7\%$

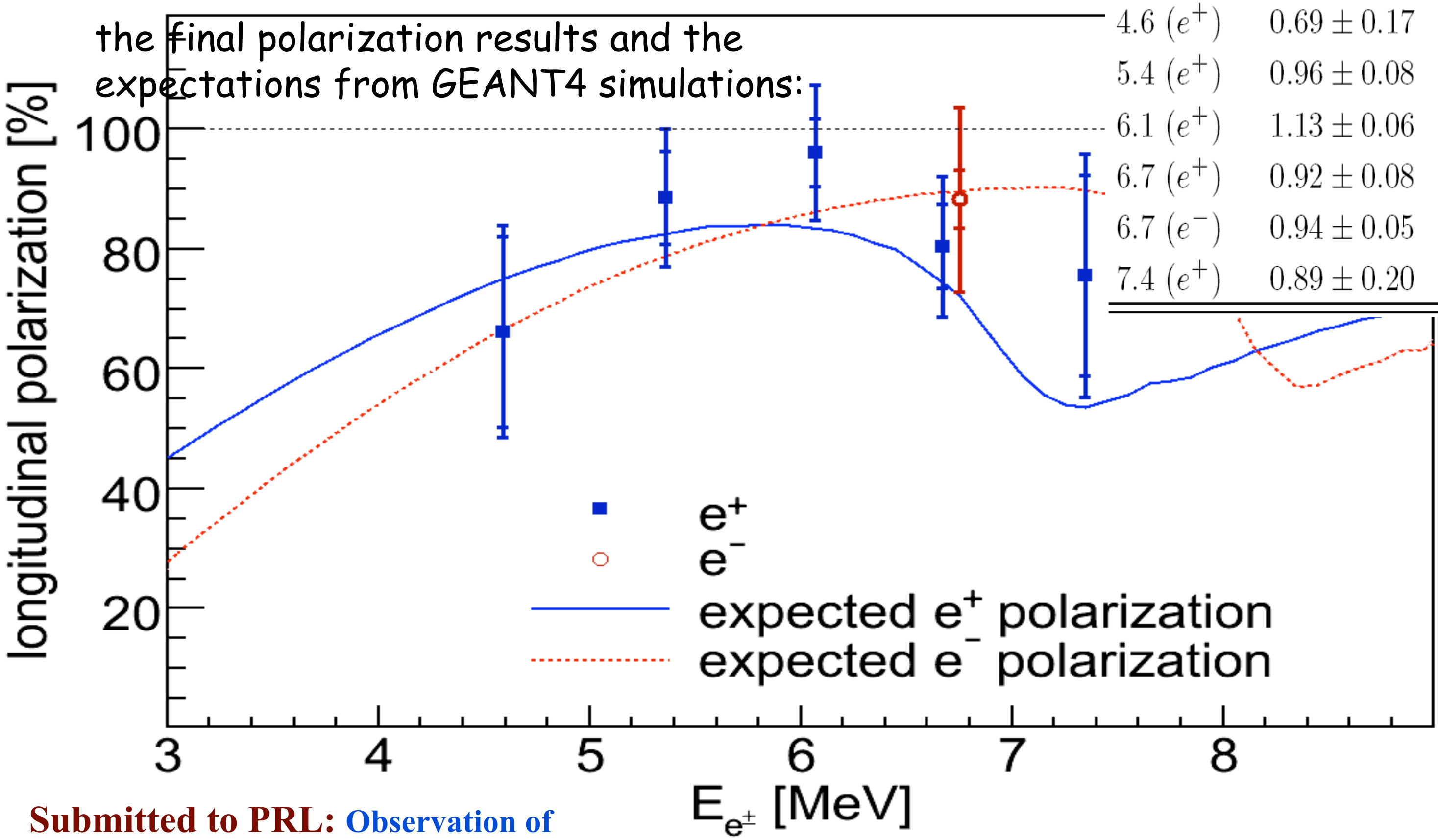
Polarization: $\delta/(nL\sigma_{pol}P_e)$

n, density; L, length (Fe); σ_{pol}, Pol.Compton cross section; P_e and P_{γ} polarization rates

POSITRON SOURCES FOR e+e- COLLIDERS: APPLICATION TO ILC AND CLIC

- **E-166: THE RESULTS** **(from R. Dollan)**

the final polarization results and the expectations from GEANT4 simulations:



$E_{e^\pm}$	$\delta \pm \sigma_\delta(\mathrm{stat})$	A	$P \pm \sigma_P(\mathrm{stat}) \pm \sigma_P(\mathrm{sys})$
4.6 (e^+)	0.69 ± 0.17	0.150	$66 \pm 16 \pm 8$
5.4 (e^+)	0.96 ± 0.08	0.156	$89 \pm 8 \pm 9$
6.1 (e^+)	1.13 ± 0.06	0.162	$96 \pm 6 \pm 10$
6.7 (e^+)	0.92 ± 0.08	0.165	$80 \pm 7 \pm 9$
6.7 (e^-)	0.94 ± 0.05	0.153	$88 \pm 5 \pm 15$
7.4 (e^+)	0.89 ± 0.20	0.169	$76 \pm 17 \pm 12$

$E_{e^\pm}$: $e^\pm$ energy
δ : asymmetry
A : analyzing power
P : polarization

Submitted to PRL: **Observation of Polarized positrons from an undulator source**