A POSITRON SOURCE USING CHANNELING IN CRYSTALS FOR LINEAR COLLIDERS

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- ## ABSTRACT

- An alternative to the conventional positron source using intense electron beams, of some GeV, impinging on thick amorphous targets is presented. This source uses two successive targets: the first one is a tungsten crystal which <111> axis is aligned with the beam direction and the second is an amorphous target put at some distance from the crystal. The enhanced radiation due to electron channelling produces a large amount of photons which consecutively create high quantity of e+e- pairs in the amorphous target. Between the two targets a sweeping magnet takes off all or part of the charged particles coming out from the crystal. An optimization procedure is carried out based on two important parameters: a) the distance between the two targets; b) the minimum energy above which the charged particles coming out from the crystal are allowed to hit the amorphous target. This optimization, which first step is presented here, aims to obtain the highest accepted yield (≥ 1e+/e-) after the capture system and the minimum Peak Energy Density Distribution (PEDD ≤ 35 J/g) in order to avoid thermal gradients which are destructive for the targets. A figure of merit, concerning both the yield and the PEDD will be derived later from this study for CLIC and ILC.

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- **INTRODUCTION**
- **For future linear colliders it is important to have very performant positron sources. If polarized sources are the best suited, it is also wise to improve the capabilities of unpolarized sources. High yield and low emittance are required; however, the level of energy deposited in the target is of extreme importance as shown by the breakage of SLC target. If elaborated cooling systems can be foreseen to absorb the mean energy deposited, the instantaneous energy deposition in a pulse duration can provoke thermal gradients leading to mechanical stresses with the target breaking as a result. The analysis operated on the SLC target showed that a limit of 35 J/g on the Peak Energy Deposition Density (PEDD) in the W target had to be respected.**
- **The channeling experiment WA 103 made at CERN provided large amounts of photons due to channeling radiation and, consequently, high yields of positrons. An hybrid target associating a crystal-radiator and an amorphous-converter gave good results. The CERN results have been confirmed and extended with KEK tests.**
- **Recent simulations showed that an hybrid target made of a thin crystal followed by a thicker amorphous target with a sweeping magnet in between allowed high positron yields AND low PEDD**

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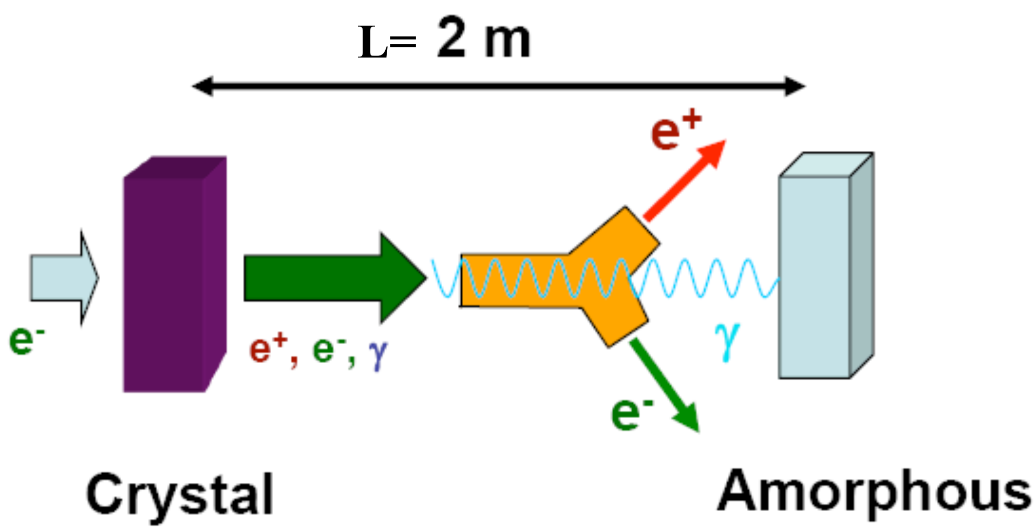
- **THE HYBRID TARGET**



The photons from the crystal are impinging on the amorphous target; the e- and e+ can be swept off or partially sent to the amorphous target. Distance L is taken 1.5 to 4 m

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- * THE CRYSTAL : Photons generated by electrons in channeling conditions and above barrier.
- * The crystal, axially oriented, may be W, Si, Ge, C(d)…
- In our case, we choose W in <111> orientation
- * THE AMORPHOUS CONVERTER: it is made of W
- * THE DISTANCE RADIATOR-CONVERTER: it is of some meters; here it is 2 meters. It allows the use of sweeping magnet in between. Another possibility is to select also charged particles coming from the radiator (e+, e-) with energy larger than $E_{treshold}$ to increase the yield e+/e-
- * IMPINGING ENERGY: E- = 5 to 10 GeV; the incident electron beam can be provided by an ERL (Energy Recovery Linac)

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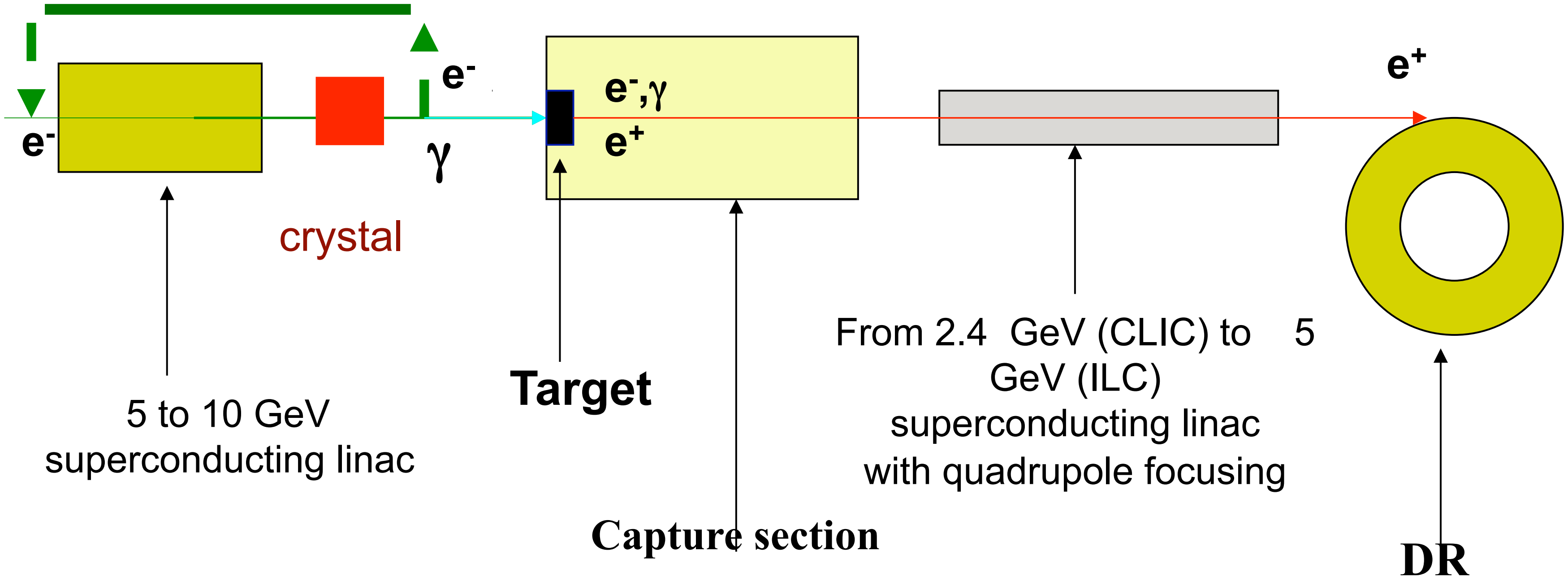
THE SCHEME



E = 270 MeV

ERL OPTION

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- **SIMULATIONS**
- **Incident beam: the electron beam energy is of 5 GeV (CLIC) or 10 GeV (ILC) and transverse rms radii of 1 and 2.5 mm have been considered**
- **Targets: W Crystal: thickness: 1.4 mm (CLIC) & 1 mm (ILC)**
- **Amorphous W target, 10 mm thick (CLIC) & 8mm thick (ILC)**
- **Capture system: an Adiabatic Matching Device with a magnetic field decreasing from 7 Teslas to 0.5 Teslas on 21 cms. Iris aperture is ~20mm radius (L-Band, 1.5 GHz). Accelerating field is 25 MV/m peak value.**
- **Outputs: Simulations have been carried out corresponding to the general scheme. The accepted yield e+/e- and the Peak Energy Deposition Density (PEDD) have been determined. The number of positrons accepted at the target (transverse and longitudinal acceptances) as the PEDD have been calculated for the 2 cases described hereafter.**

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- **SIMULATIONS RESULTS**
- **Two cases have been considered:**
- *** Only the photons are impinging on the amorphous target**
- **All the charged particles coming out from the crystal are swept off. The e+ exiting from the amorphous converter are coming from showers generated by the photons due to channeling radiation, coherent bremsstrahlung, ordinary bremsstrahlung in the crystal.**
- *** The photons and some of the charged particles generated in the crystal are impinging on the amorphous converter**
- **The shower providing the positrons in the amorphous converter is generated by the photons and electrons (positrons) above an energy threshold determined by the magnetic field in the sweeping magnet and the collimation.**

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- **PEDD: A RECALL**
- **The local and almost instantaneous energy deposition in a target (for instance, during a pulse duration) may be very critical for the target survival. In effect, 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 breaking, analyses undertaken at LANL and LLNL showed that a maximum value of 35 J/g (for W) must not be exceeded. So, an accurate determination 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 the maximum value (generally in the cylinder of smallest radius at the exit end of the target) is determined for the PEDD. This quantity is to be compared to the value of 35 J/g.**

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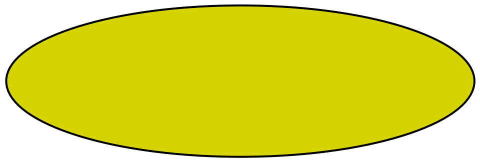
- **ACCEPTANCE CONDITIONS**
- **The accepted e+ are contained in the transverse phase space defined by the acceptance ellipse at the target:**
- $[r/0.53]^2 + [p_T/11]^2 = 1$; **r is in cm and p_T in MeV/c**



- **The longitudinal momentum p_L is taken between 1.3 MeV/c (debunching) and 17.3 MeV/c (adiabatic condition)**
- **The longitudinal and transverse momenta satisfy the relation:**
- $p_T < 0.1875$ **MeV/c** $+ 0.625\, p_L$ **; this relation corresponds to a maximum positron angle of ~32 degrees which put a limit on the debunching (in an L-Band accelerator) with the focusing fields considered.**

These acceptance conditions correspond to an AMD /{7 →0.5 Tesla on 21 cms} and to a limit of 15 mm for debunching (see CLIC Note 465)

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- **THE CASE OF CLIC**

- SIMULATION RESULTS FOR γ **GENERATED SHOWER**
- **ACCEPTED POSITRON YIELD**
- *** For an incident e- beam with σ = 2.5 mm => η = 1.28 e+/e-**
- **PEDD**
- **Assuming an incident e- pulse of 2.34 10^{12} e-, we have :**

	CRYSTAL		AMORPHOUS	
	PEDD/e- (GeV/cm3/e-)	PEDD/total J/g	PEDD/e- (GeV/cm3/e-)	PEDD/total J/g
σ=1mm	2	38	2.5	48.5
σ=2.5mm	0.35	6.8	0.8	15.5

- **An entirely amorphous target, 9 mm thick, with the same incident e- beam would have provided the same accepted yield and a PEDD of 150 J/g (σ=1mm) or 40 J/g (σ=2.5 mm). This shows the advantages of an hybrid scheme leading to a unique target with a PEDD < 35 J/g using an e- beam with σ= 2.5 mm. The average power deposited in the target is < 4 kW.**

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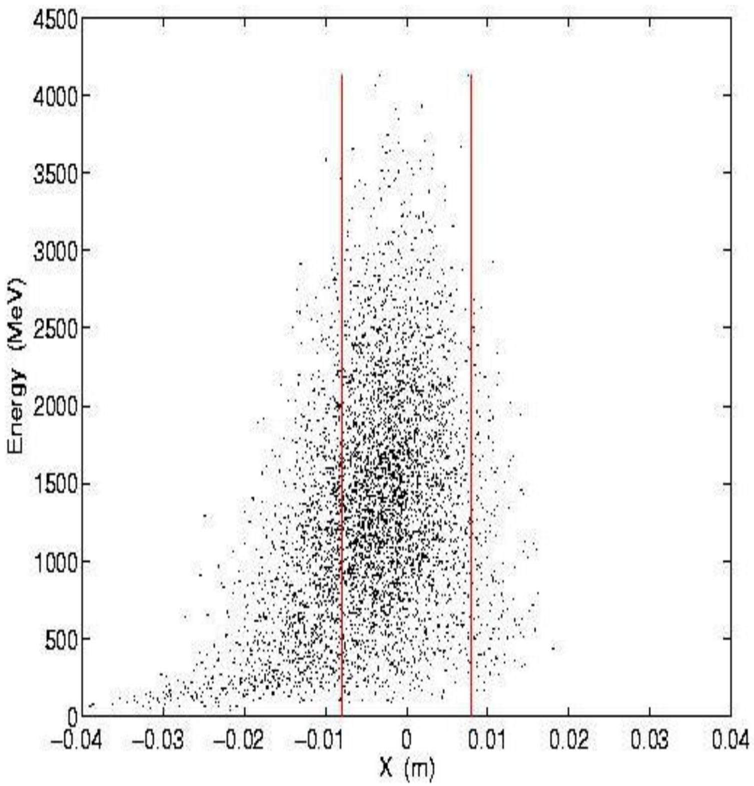
- **POSITRONS GENERATED BY γ, e- AND e+ COMING FROM THE CRYSTAL**
- **The e- (and e+) coming out**
- **from the crystal are sent to**
- **the amorphous target**
- **together with the γ.**
- **We show, here, the e- on the**
- **target after being bent by the**
- **sweeping magnet which**
- **selects particles with B= 500**
- **gauss. The geometrical limits**
- **of the target are in red; they**
- **correspond to ± 8 mm.**
- **Highest particle density inside**
- **the limits is over 500 MeV.**



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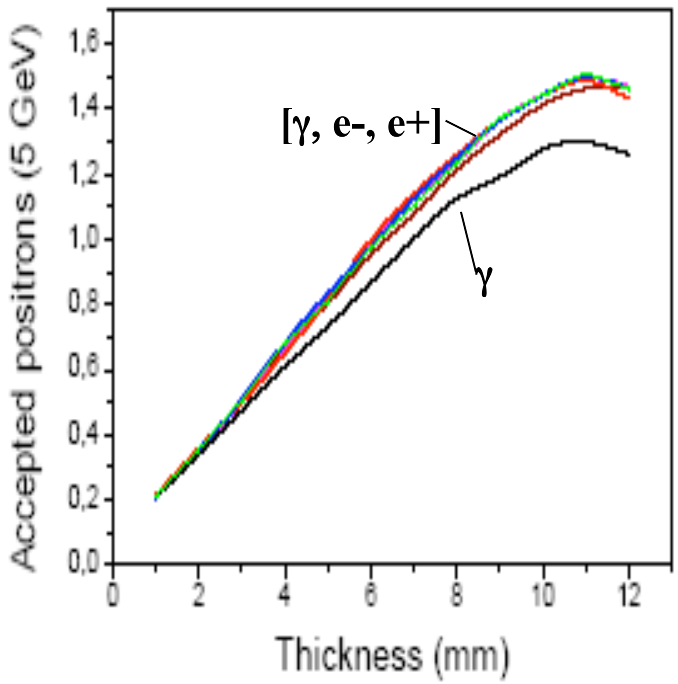
- **THE CASE OF CLIC**
- POSITRON SOURCE GENERATED BY γ AND e-, e+ COMING FROM THE CRYSTAL: comparison for the accepted yields (threshold energies are between 50 and 900 MeV)
- For 10 mm amorphous target, the yields are:
- * 1.28 (only γ)
- **∗ 1.44 (e-, e+, γ)**



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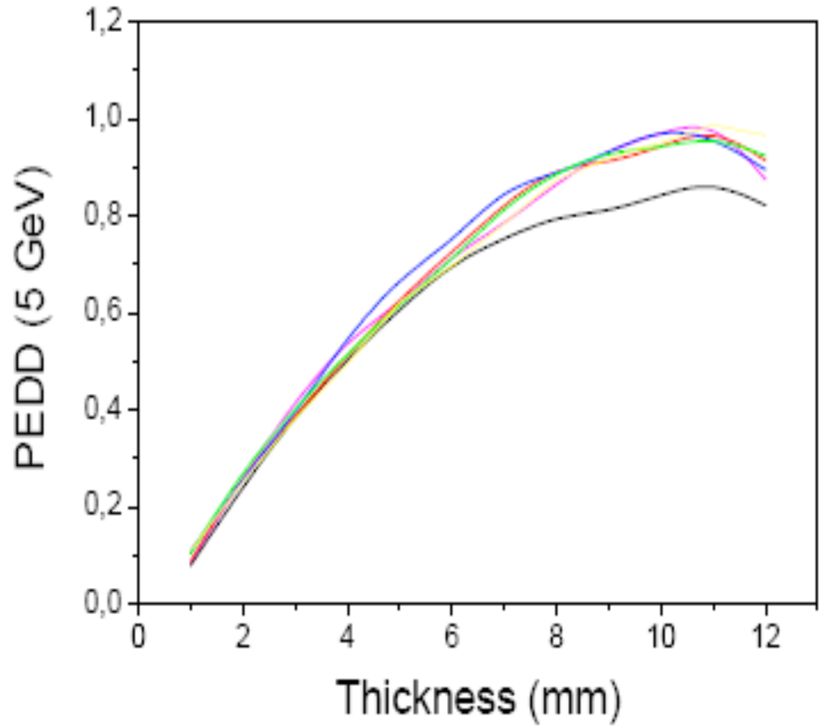
- **THE CASE OF CLIC: PEDD**
- **On the figure the PEDD is given**
- **in GeV/cm^3/e-**
- **The PEDD is growing from**
- **0.80 GeV/cm^3/e- to a mean**
- **value of 0.96 GeV/cm^3/e- when**
- **sending photons, e- and e+**
- **emitted at the crystal on a**
- **10 mm thick amorphous target**
- **That brings the PEDD per CLIC**
- **Pulse to less than 18 J/g, well**
- **below the 35J/g limit. Threshold**
- **Energies are: 50 →900 MeV**



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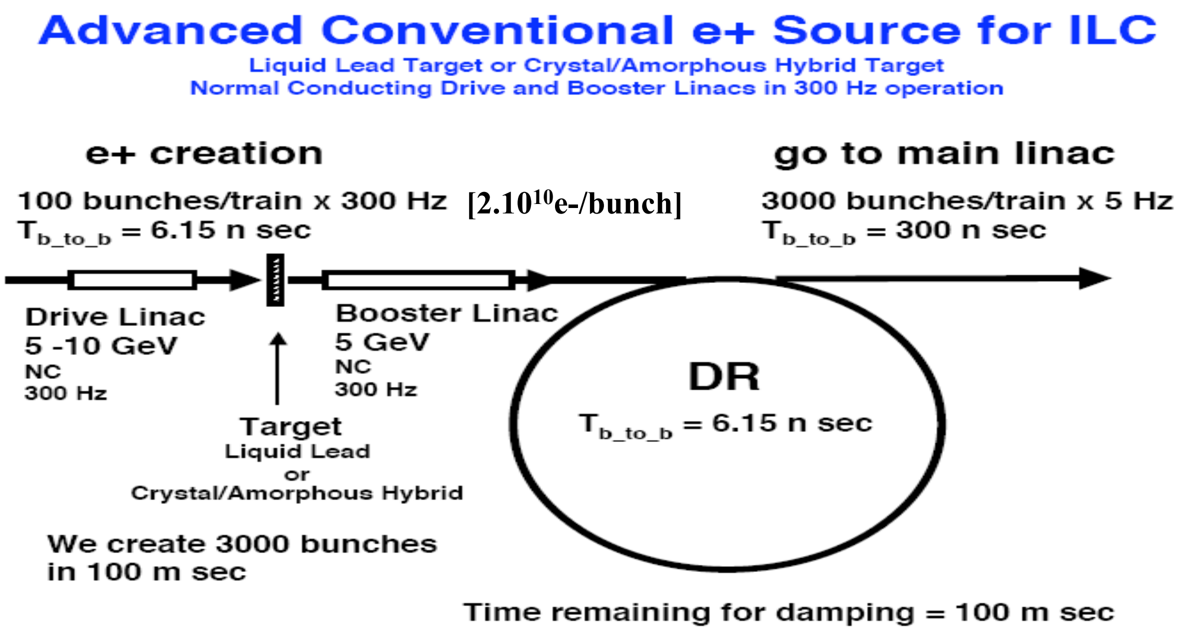
- **THE ILC CASE**
- **Due to very intense pulses, the hybrid option for ILC need a preliminary transformation of the incident beam on the targets to preclude immediate destruction**



Scheme proposed by T.Omori

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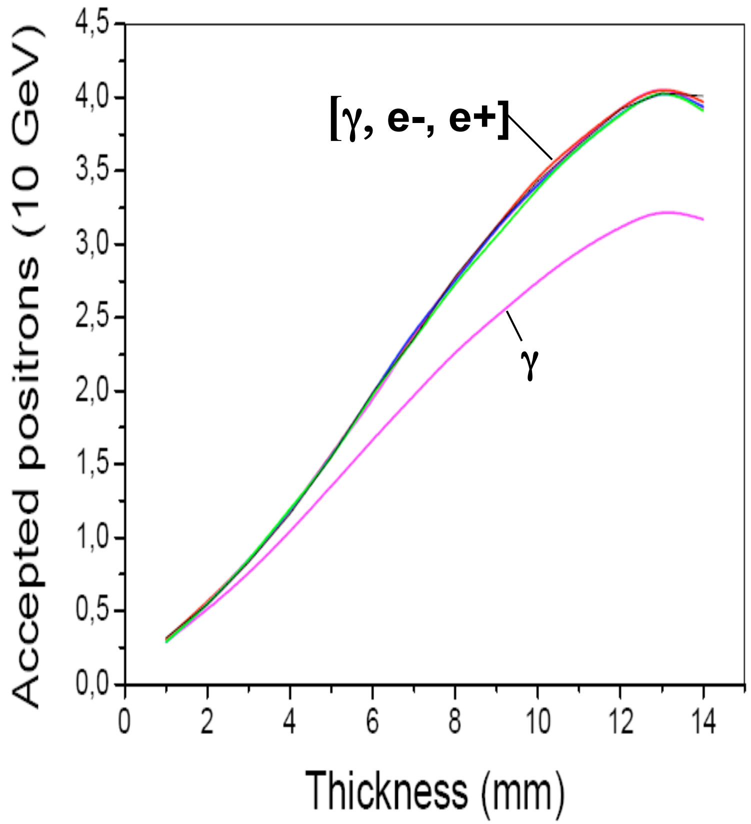
- POSITRON SOURCE GENERATED
- BY γ AND e-, e+ COMING FROM
- THE CRYSTAL: COMPARISON
- FOR THE ACCEPTED YIELDS
- For 1 mm thick crystal (W) and
- 8 mm thick amorphous target
- and incident energy of 10 GeV
- and an e- beam with σ=2.5mm
- The yields are:
- - 2.25 e+/e- (only γ)
- - 2.75 e+/e- (γ, e-, e+)
- The threshold energies are
- between 50 and 900 MeV



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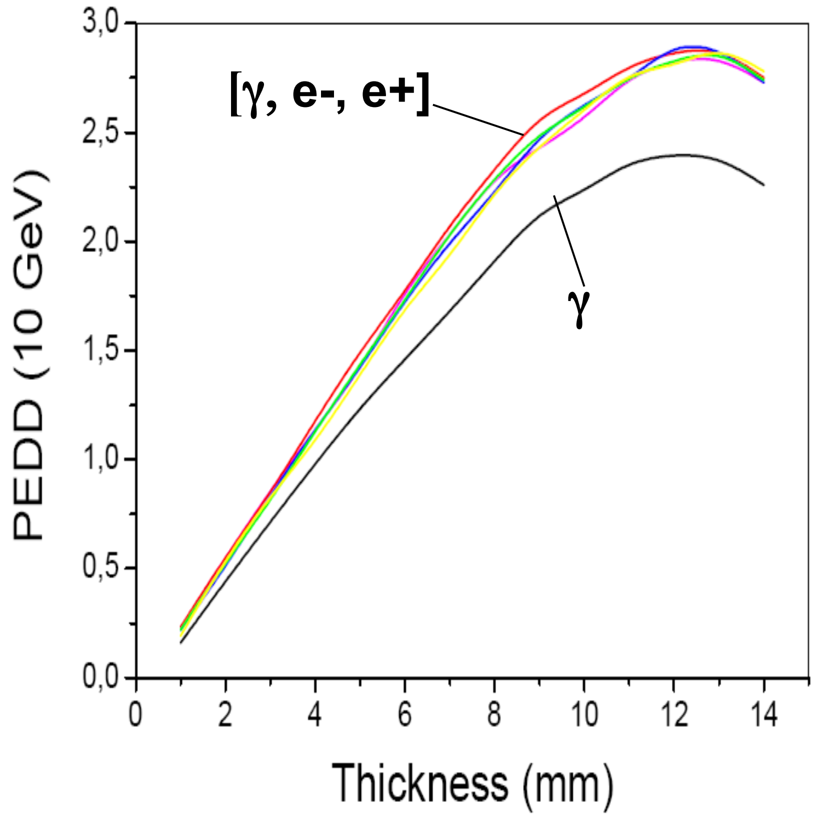
- THE PEDD
- On the figure the PEDD is
- given in GeV/cm³/e-
- The PEDD is growing from
- 1.90 Gev/cm³/e- (only γ) to a
- mean value of 2.3 GeV/cm³/e-
- (γ, e-, e+) for the 8 mm am. Tg.
- Maximum PEDD is for 13 mm
- thickness where it reaches 2.9
- That brings the PEDD per
- modified ILC pulse to 31.3 J/g, just below the limit (35J/g) for the [1mm crystal, 8 mm amorph.] targets and 10 GeV e- beam (σ=2.5 mm)



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- **PRELIMINARY CONCLUSIONS**
- **1) FOR CLIC**
- **The hybrid positron source is able to provide the needed accepted yield for CLIC. A yield of more than 1 e+/e- is reachable using only photons coming from the crystal and *a fortiori* also e- and e+ coming from the crystal and over an Energy threshold.**
- **The PEDD remains under the critical value of 35 J/g (for W) both for the thin crystal and the thick amorphous target. The energy thresholds, for which charged particles impinge also on the amorphous target are starting from 50 MeV. Most of the energy deposited (and the PEDD) is due to the photons (more than 80 %).**
- **All the results concerning the yield as the PEDD correspond to an rms radius of 2.5 mm for the incident electron beam. Such dimension is compatible with the AMD geometrical acceptance (almost 6 mm)**
- **The main results were concerning a distance of 2 meters between the 2 targets; this distance can be extended to 3 meters without problem for the yield which should remain > 1e+/e- using γ , e- and e+ as resulting from a rough evaluation**

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- PRELIMINARY CONCLUSIONS (continued)
- 2) FOR ILC
- With the parameters chosen (W crystal thickness of 1 mm; amorphous W thickness of 8 mm; incident energy E-= 10 GeV; beam incident rms radius σ= 2.5 mm) the accepted positron yield using an AMD matching system is of 2.25 e+/e- when only photons are impinging on the amorphous target and about 2.75 e+/e- when also e- and e+ above 50 MeV are allowed to impinge on the amorphous target. This is satisfying the ILC requirements.
- Concerning the PEDD the modification of the incident beam before the target, as defined above, leads to a PEDD/pulse (2.10^{12}e-/pulse) of 31.3 J/g, which is just below the limit of 35 J/g. However such a solution is to be checked with the actual thermal behaviour of the target and needs further investigations. Anyway, the use of an hybrid target (with all its advantages) needs a preliminary transformation of the nominal ILC pulse, restoring its time structure after the positron target.
- As for CLIC, the optimization of the parameters of the hybrid source can be operated.