AN HYBRID POSITRON SOURCE USING CHANNELING FOR ILC

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- **INTRODUCTION**
- **There is a strong interest in having a performing positron source for the future linear colliders.**
- **Performance means: high intensity, 6D emittance matched for the DR injection, and low energy deposition and PEDD**
- **For unpolarized positrons , use of conventional sources (high intensity incident beam, thick amorphous targets) leads to some inconvenients regarding the emittance of e+ beam and a rather high energy deposition and PEDD.**
- ***Remedy? multiple-target system (A) or rotating targets (B)***
- ***Or hybrid sources using channeling: our choice***
-

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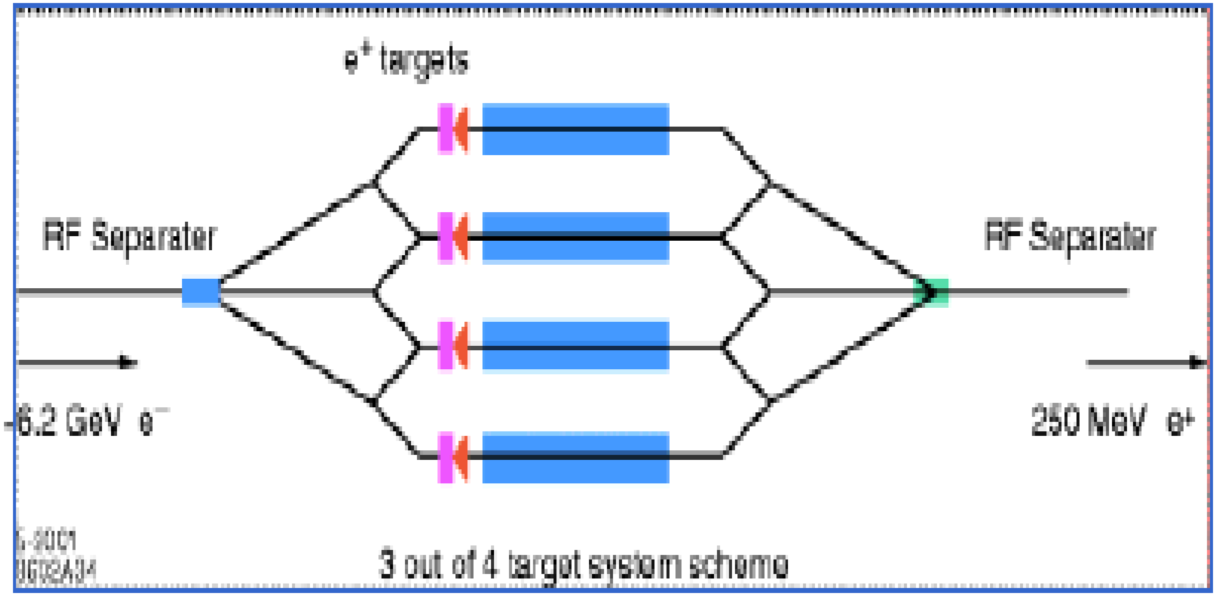
A solution: the multi-target system (A)



From J.Sheppard (NLC)

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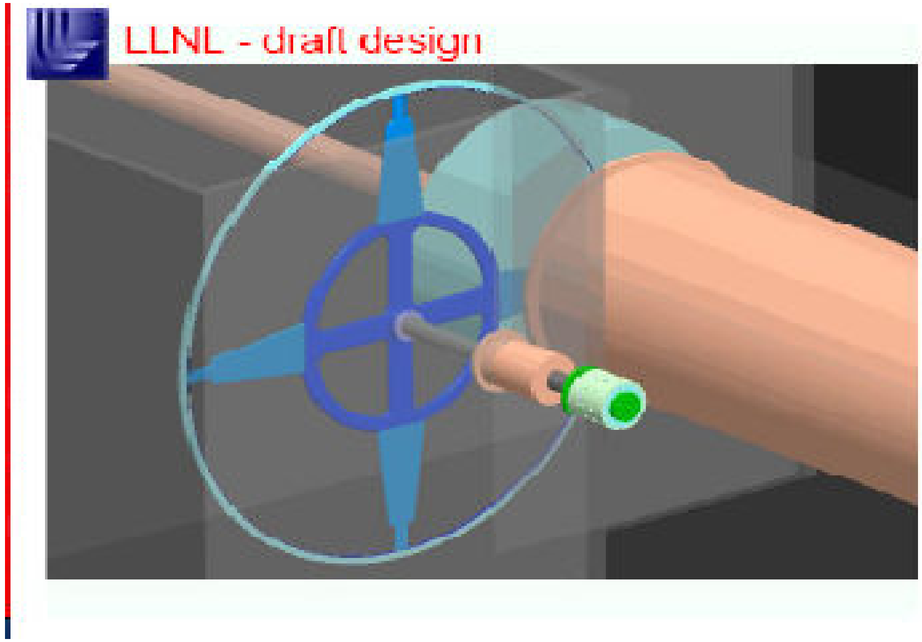
- **The rotating target (B): from Ian Bailey**



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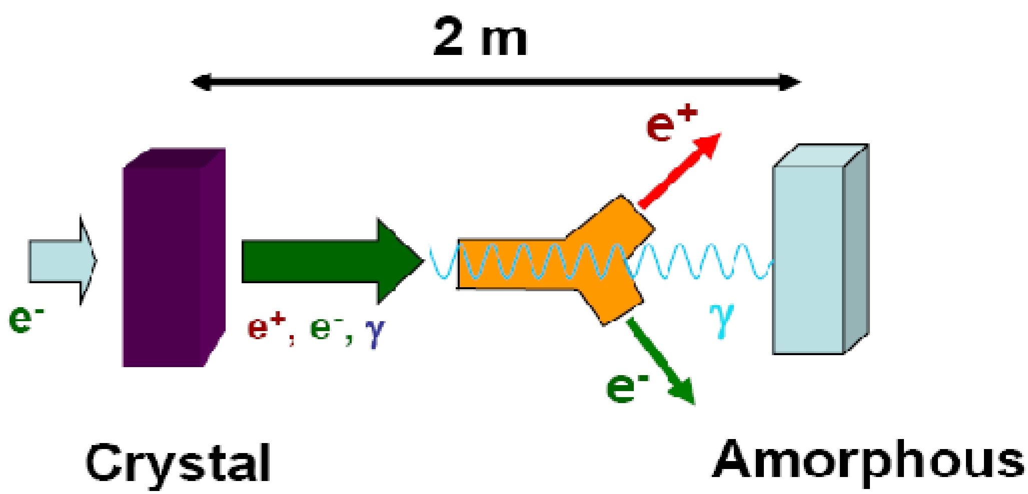
R.Chehab, V.M.Strakhovenko, A.Variola



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 hybrid e+ source using channeling**
- **High energy e- (some GeV) impinging at glancing angles to the main axes of an oriented crystal radiate a large number of soft photons (some tens of MeV, typically) ; this is much more than with ordinary bremsstrahlung in amorphous targets of the same material and thickness; works like an atomic undulator**
- **Successful experiments at CERN (WA103) and KEK**
- **If we separate the photon radiator from the e+ converter and use only the photons (and eventually part of the e+, e-) coming out from the crystal, we may lower considerably the level of PEDD. A practical consequence is the possibility in some cases of using 1-target system, only. Studies on conventional e+ sources at KEK are also carried out to minimize the effects of heating (PEDD,..)**
- **=> Choice of such hybrid system for unpolarized e+ of CLIC**

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- **IS SUCH SYSTEM APPLICABLE FOR ILC ?**
- **The main problem: very high beam intensity which could destroy the targets. To avoid this difficulty, we may think about a modification of the beam structure before the target to lower the number of particles per pulse which is one of the main parameters for the PEDD. The separation between pulses is determined in order to allow the thermal shock wave to damp. After e+ production capture and acceleration the DR restores the nominal time distribution.**
- **Two solutions are considered:**
- **- the 300 Hz (T.Omori, KEK)**
- **- the 45kHz/5Hz (A.Variola, LAL)**

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- We present here some simulations concerning the hybrid positron source with results on the yield, emittance, energy distribution, capture,..
- Two incident energies will be considered: 8 and 10 GeV. The crystal thickness will be 1mm and the amorphous target thickness will be taken between 6 and 10 mm. The distance between the crystal-radiator and the amorphous-converter will be chosen between 2 and 3 meters to allow enough place for a sweeping magnet.
- A presentation of the two solutions for lowering the PEDD with the results on the calculations of the PEDD and the associated mechanical stresses in the targets will follow.
- The simulations use the results of Strakhovenko's code with GEANT4 (O.Dadoun)

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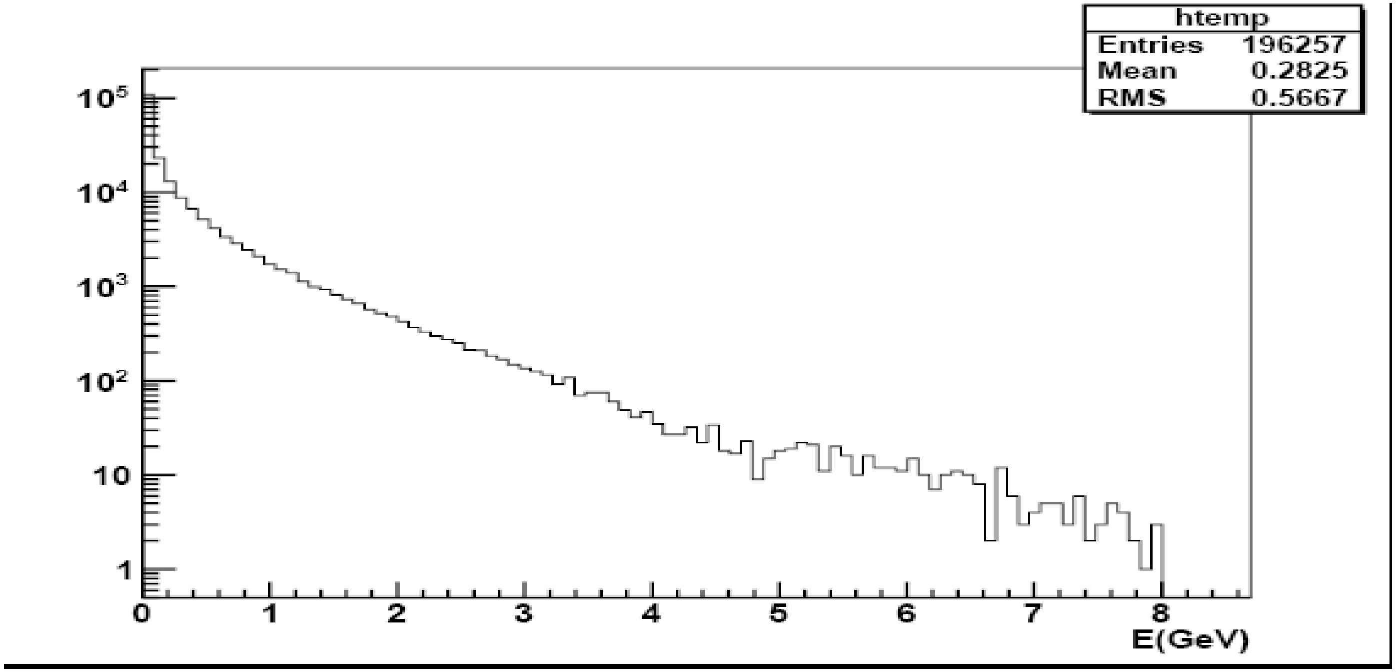
THE PHOTON BEAM

Energy spectrum and transverse distribution E-=8 GeV



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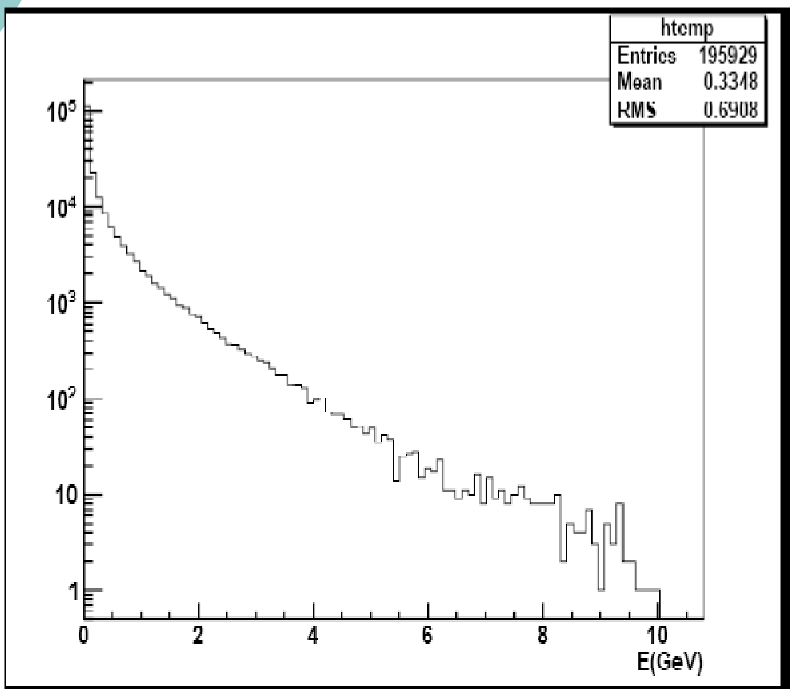
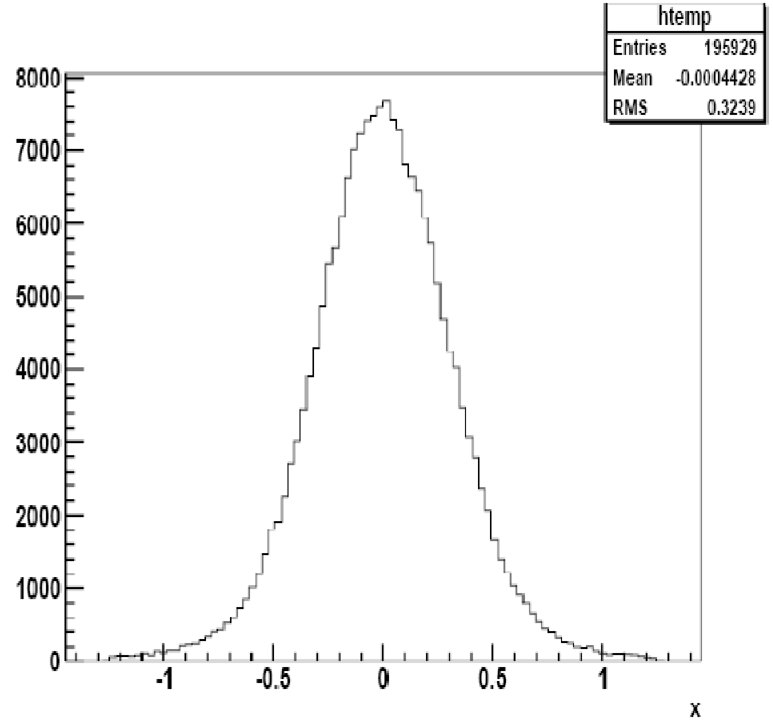
- **The photon beam**
- **Energy spectrum, transverse distribution E-=10 GeV**





Dimension in cm

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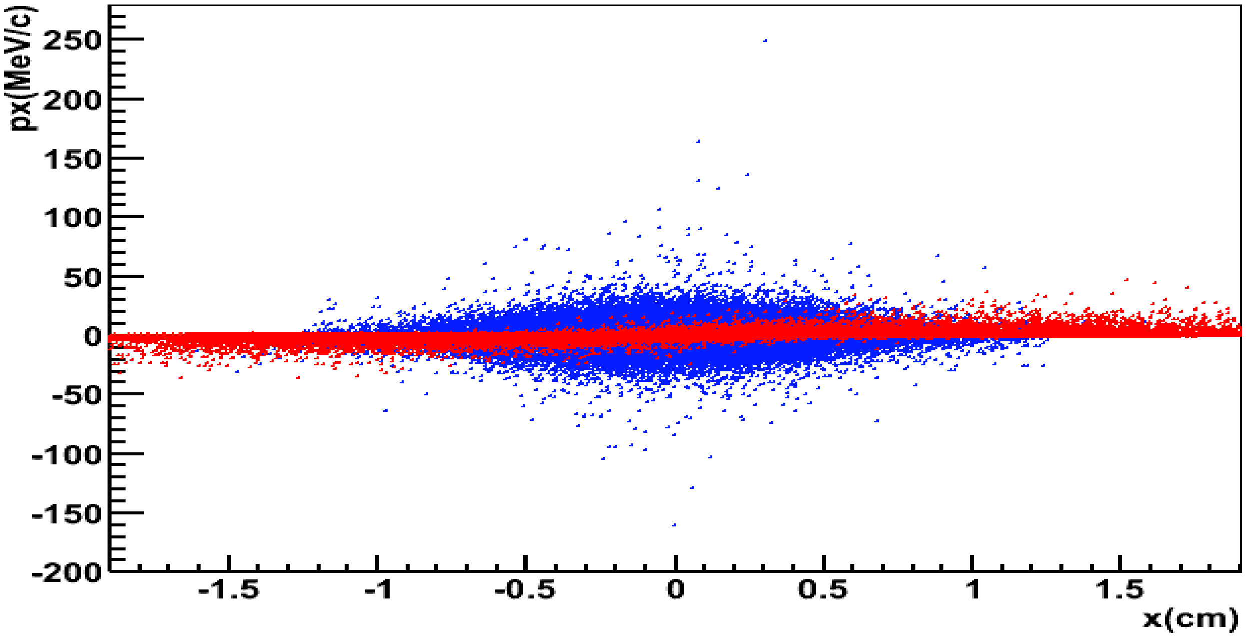
- **The positron beam [E-= 10 GeV]**
- **Transverse emittance distribution (at target (blue) and at AMD end (red))**



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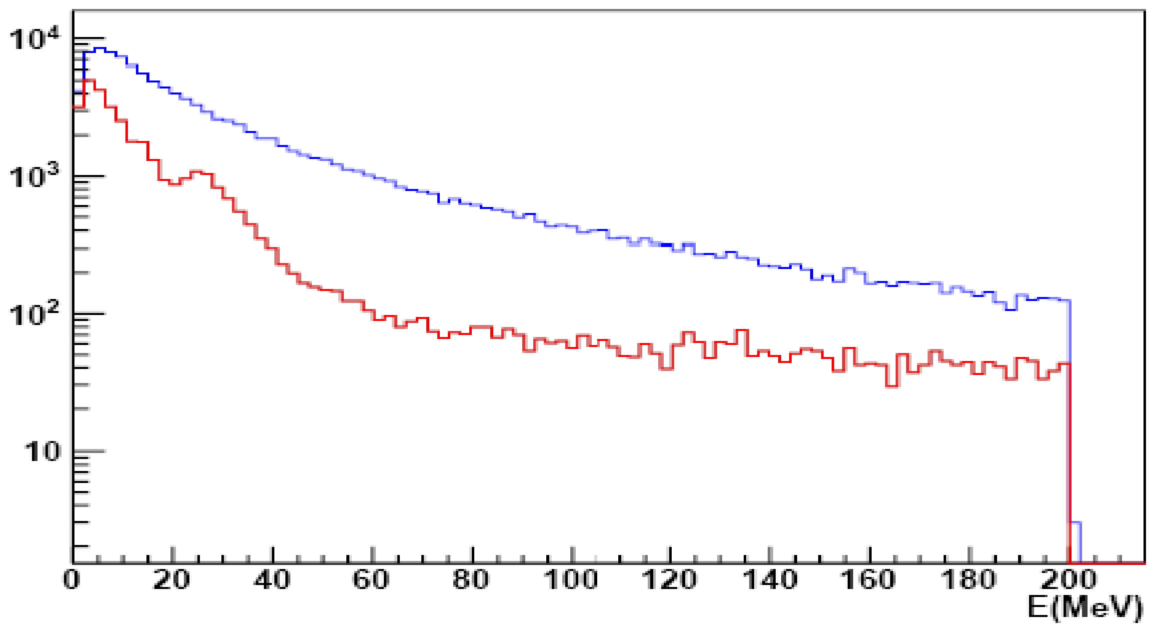
- **The positron beam [E-=10 GeV]**
- **Energy spectrum (at target, AMD)**



The AMD acts as a low energy filter for the positron beam

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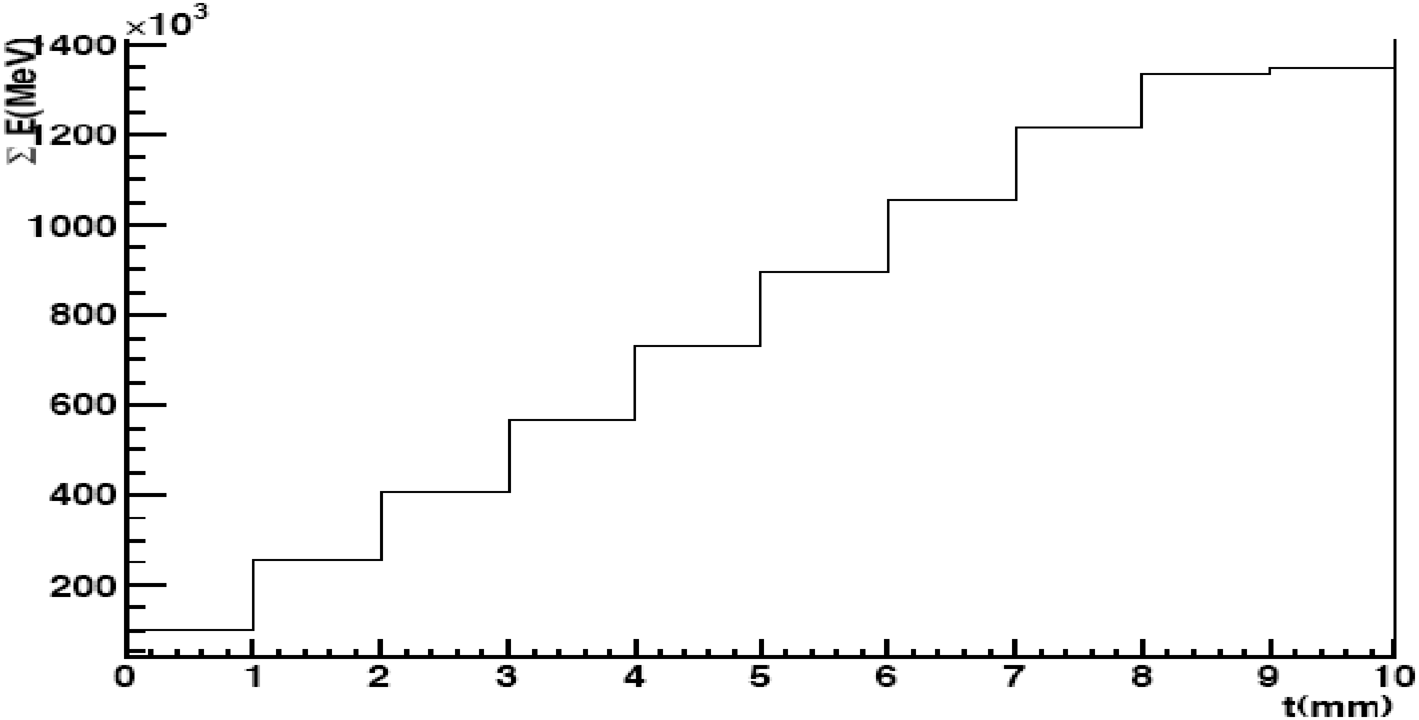
- **DEPOSITED ENERGY**



The incident e- beam is at 10 GeV: the total deposited energy in a 8 mm target is: ~520 MeV/e-. 10000 e- have been simulated

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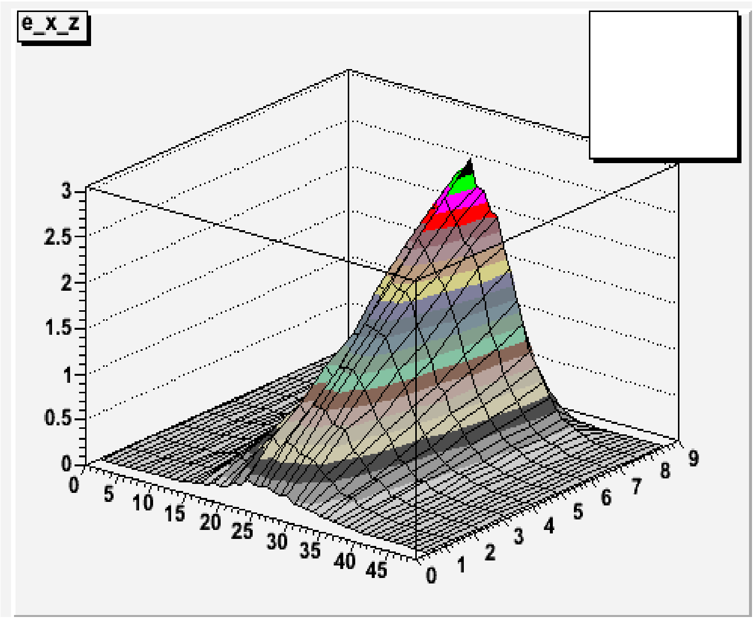
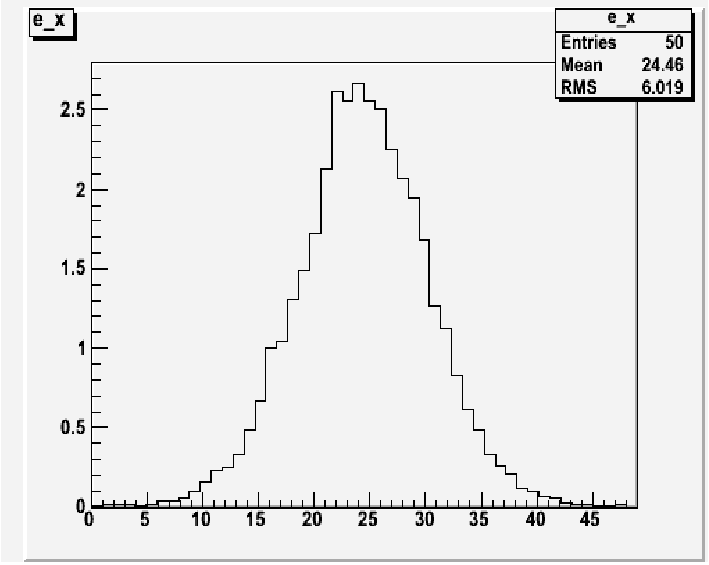
- **ENERGY DEPOSITION DENSITY: E- = 10 GeV**
- **L(Xtal)=1mm; L(amorphous)= 10mm: distance= 2 m**

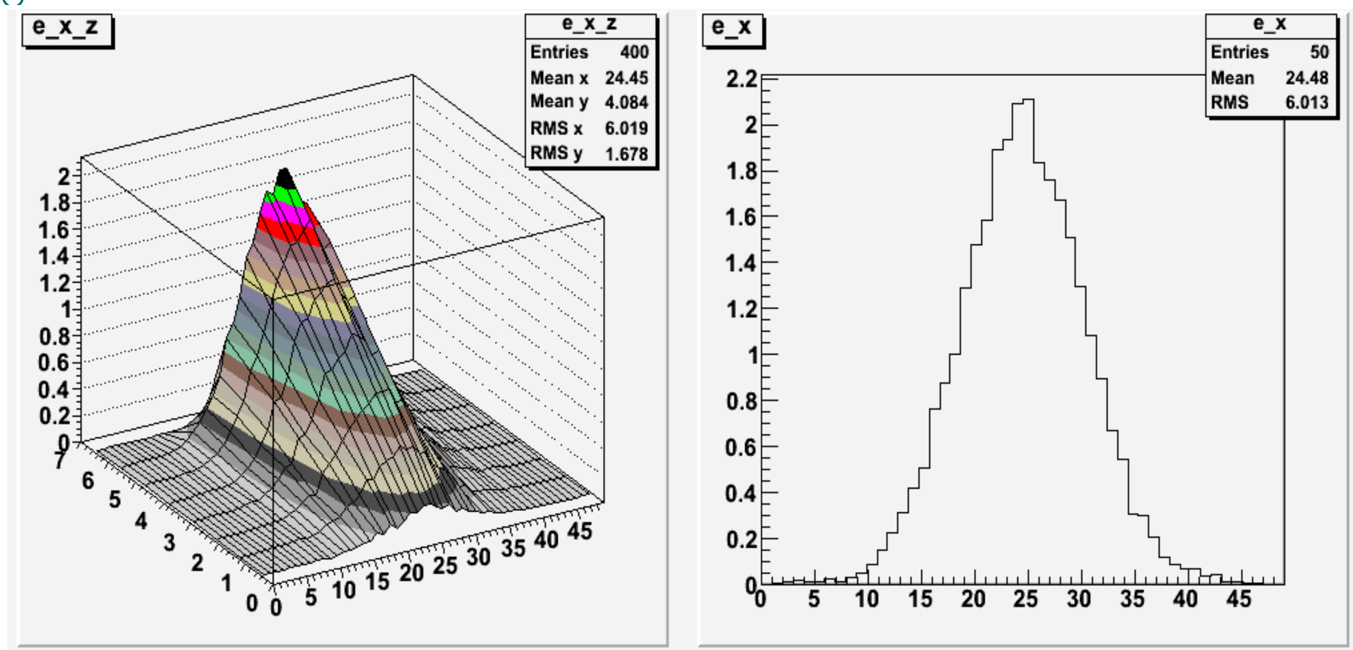




PEDD→ 2.7 GeV/cm^3/e- ; e- rms radius: 2.5 mm

AN HYBRID POSITRON SOURCE USING CHANNELING FOR ILC

- **ENERGY DEPOSITION DENSITY: E-=10 GeV**
- **L(Xtal)= 1mm; L(Amorphous)=8 mm; distance=2 m**
-



PEDD→ 2.11 GeV/cm^3/e- ; e- rms radius: 2.5 mm

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- **The positron beam: the yield (t_{am}=8 mm)**

	Target	AMD end (with B_r)	Accel (150 MeV)
E-=8 GeV	11	3.7	2.3
E-=10GeV	13.4	4.7	2.9

- **The distance between the two targets is 2 meters**
- **The solenoid at B=0.5 Tesla extends over the accelerated part**
- **The accepted yields present enough margin to realize 1e+/e- at IP.**
- **NB: a rough calculation with simple focusing formulation gave smaller values of accepted yields at AMD (-20%)**

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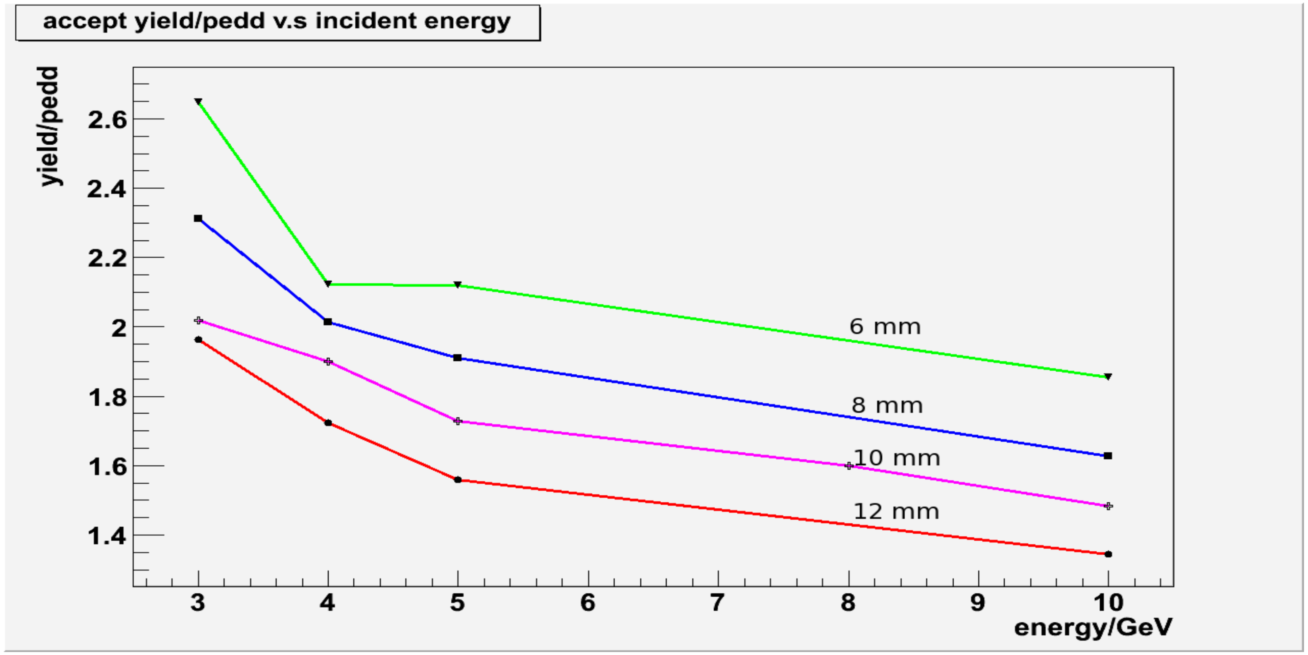
- **A FACTOR OF MERIT FOR e+ SOURCES: η^+/PEDD**
- **The ratio: [accepted yield at AMD end/PEDD] is represented; the accepted yield is at AMD end; the amorphous thickness is indicated on the curves. The PEDD is in GeV/cm^3/e-**



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- **ENERGY DEPOSITED, THERMAL GRADIENT, PEDD AND SHOCK WAVES (a semi-quantitative approach)**
- **The high intensity incident electron pulses are depositing a large amount of power in the targets provoking temperature rise. The target material expands but due to the mass inertia, there will be a delay leading pressure waves to cross the material provoking stresses. These waves move with the sound velocity,**
- $v = [E/\rho]^{1/2}$
- **Where E is the Young modulus and ρ the density.**
- **The time needed to the wave to travel from the outer surface to the centre is $\tau_s = d/v$. For target radii of 1 cm, that represents ~ μs . If the pulse width $\tau_p > \tau_s$, small amount of energy is going in the target in τ_s and the shock is limited.**

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- **ENERGY DEPOSITED, THERMAL GRADIENT PEDD AND SHOCK WAVES**
- **After the breaking of the SLC e+ target analyses and tests have been undertaken (LLNL, LANL, SLAC). Particularly, the timescales of the different phenomena were determined. It came out that the stress level due to the temperature gradient was lower than the instantaneous shock (see Vinod Bharawadj).**
- **The timescale of the shock wave is of some μs ; so if we spread out the initial ILC pulse in order to have short pulses separated by intervals of microsecond level, a solution can be available.**

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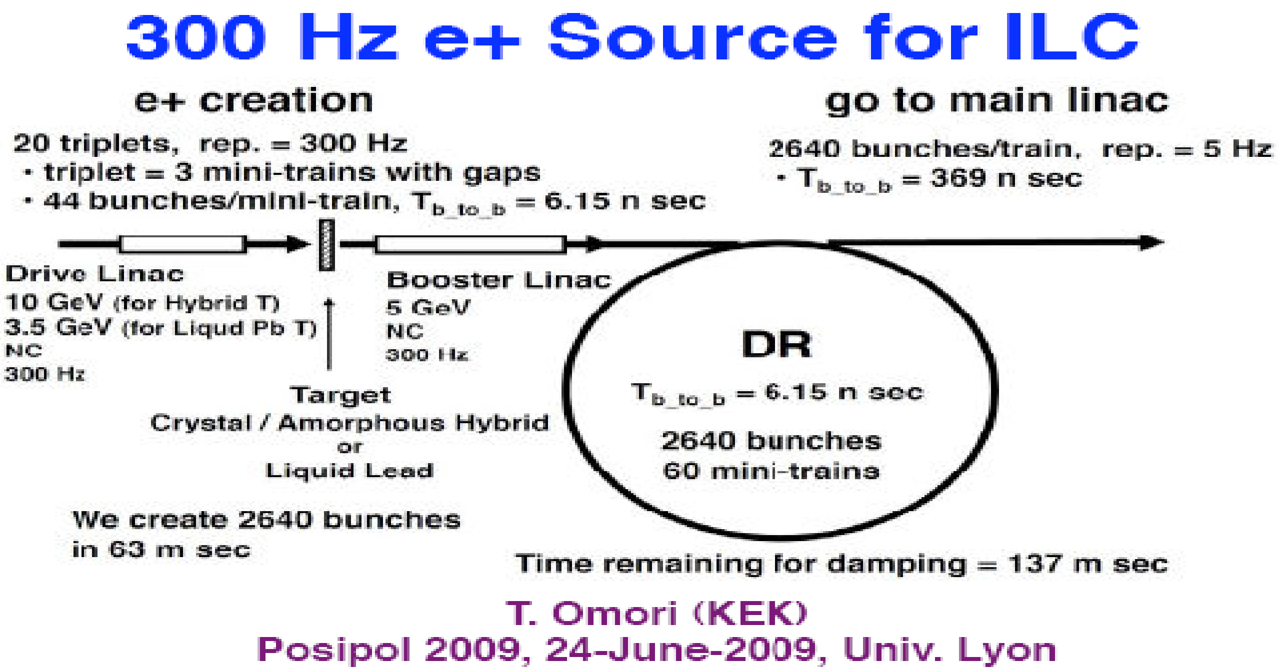
- **1- THE 300 Hz scheme (KEK)**



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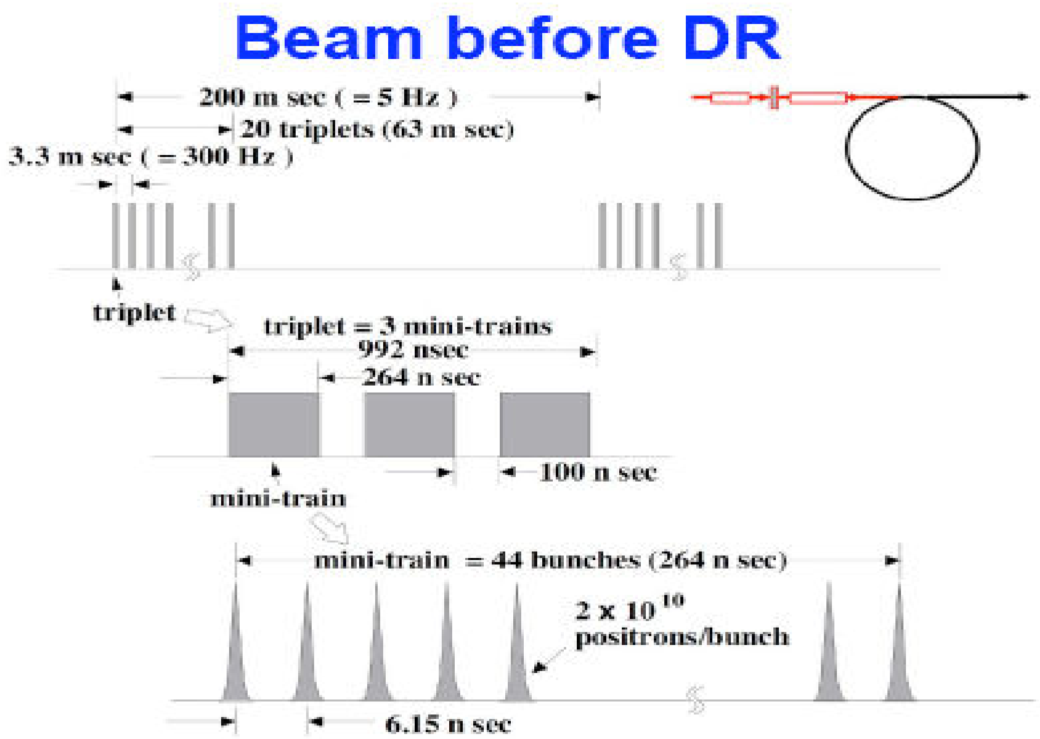
- **The 300 Hz scheme**



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- **The 300 Hz scheme**
- **Referring to the timescale presented above and considering a PEDD of 0.33 J/g per ILC bunch of 2.10^{10} e-, we have (see T.Omori/ POSIPOL 2009):**
- **- a PEDD of 44 J/g for 132 bunches (triplet)**
- **- a PEDD of 14 J/g for 44 bunches (mini-train)**
- ***Between 2 successive mini-trains: 100 ns.***
- ***Between two successive triplets: ~3.3 ms, enough to damp the shock wave.***

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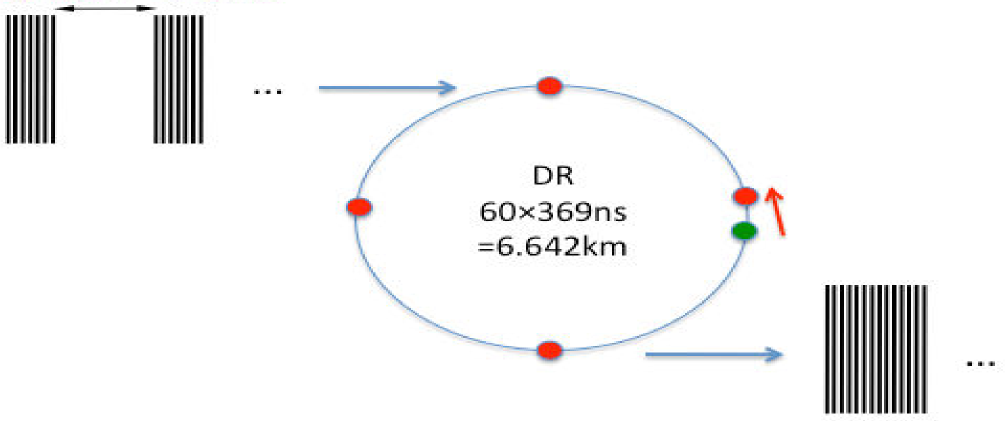
- **2- The 45kHz/5Hz solution (LAL) ; μpulse:22.14 μs**

Initial (before DR)
- 44 micro trains separated by 11.06 μs
- 1 micro train is composed by 60 bunch
- Each bunch are separated by 369 ns
- Total bunch train ~ 1.46 ms



Final (after DR)
- 2640 bunch separated by 369 ns
- Total bunch train ~ 1. ms

Bunch population 2×10^{10}

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- **The 45kHz/5Hz solution**
- **The PEDD per bunch is of 0.33 J/g ; it is of 20 J/g for a micropulse.**
- **The micropulse duration (22.14 μs) is much larger than the time needed for the shock wave to travel from the outer surface to the centre (~ 3 μs, for a target having r=L ~1cm)**
- **Such situation where $\tau_p > \tau_s$ is favourable => see P.Sievers/CERN**
- **The first micropulse is filling the damping ring, and after ~half the ring period, the second micropulse is filling the ring with a [22.14 μs/2 – (0.369μs/44)] delay**

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- **STRESSES IN THE AMORPHOUS TARGET**
- **For a target having a 10 mm radius and 8 mm thickness and a beam micropulse duration of 22.14 μs , the stress is given by (see P.Sievers, CERN Note LABII/BT/74-2,1974):**
- $\sigma_{max} = E\alpha To.[2L/\nu t_0]$
- **Where E, Young modulus; α, thermal expansion coefficient; To, target temperature; L, target thickness; t_0, pulse duration; ν, the sound velocity. For the W target, we get for a temperature of 1000°C:**
- $\sigma_{max} = 72$ MPa
- **We note the reduction factor of $[2L/\nu t_0]$ due to $t_0 > t_s$ where t_s is the time put by the shock wave to cross the target.**
- **This is a rough calculation; similar calculation for SLC target gave a result with a factor 2 in excess wrt finite element calculation (W.Stein et al. PAC 2001).**

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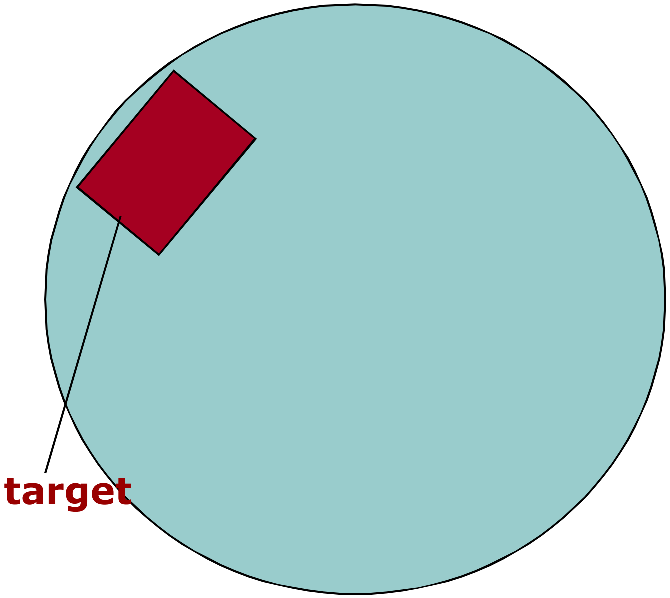
- **THE TARGET FOR THE 45kHz/5Hz: SOLUTION**
- The 5 W targets are distributed
- On a wheel rotating at 5r/sec.
- As 520 MeV are deposited by e-
- in a 8 mm target [E-=10 GeV]

Each target receives a deposited

- energy of: 1.7 J/bunch
- and 100 J/μpulse and 4.4 kJ
- per second. The target width
- is ~5cms on a wheel
- of 1 m radius. The γ beam
- spot of about r=3 mm rms
- crosses the target width
- in 1.5 ms. The beam impact
- on the target is not at the same place from the 1st to
- the last μpulse in the 1.5 ms duration.The rotation speed of the target is 31.4 m/s. This is a quite challenging assumption. The "melting density" is about 190 J/g) for W.



Ω=31.4 rad/sec; 300 rpm

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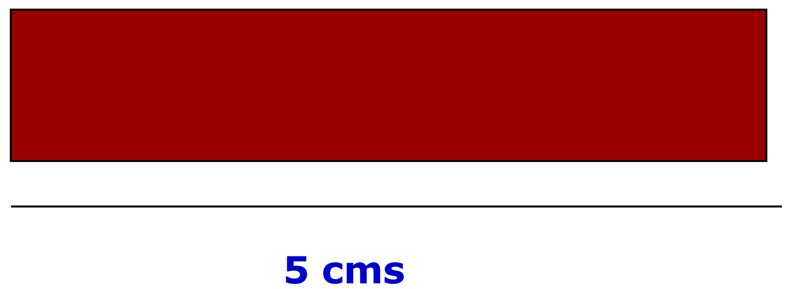
- **Deposited energy on the rotating target**



The impinging γ beam has a lateral extension of ~ 3mm rms. When the target is rotating successive μpulses are smearing partially one over the other. The distance between the peaks (corresponding to 22 μs) to overcome the smearing is ~10mm => 0.3 ms (v=31.4 m/s). That means that 10 μpulses are concerned. As the smearing is partial, we take a coefficient of 0.5; that corresponds to a complete smearing of 5 μpulses => i.e. 500 Joules. With the volume concerned (1x1x0.8 cm^3) that correponds to ~32 J/g.

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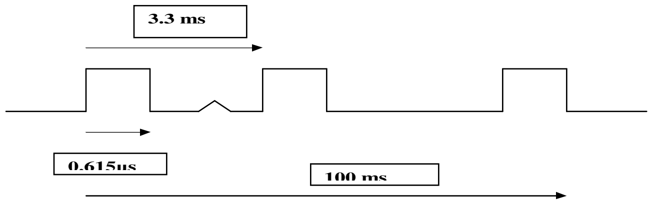
- **AVERAGE ENERGY DENSITY & PEDD [KEK]**
- **The triplet has 132**
- **bunches and deposit**
- **220 Joules in a 8 mm**
- **amorphous target**
- **(E-=8 GeV). The average**
- **Energy density is about 14 J/g**
- **The PEDD is ~ 44 J/g, with a**
- **Nominal PEDD/bunch of 0.33 J/g/bunch**
- **The separation between 2 successive triplets (3 ms) is largely enough to damp the shock wave.**



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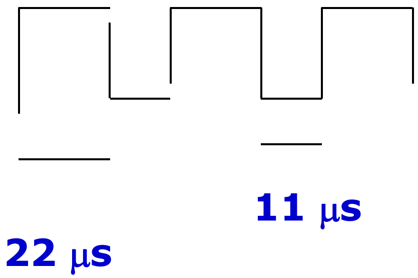
- **AVERAGE ENERGY DENSITY & PEDD [LAL]**



The micropulse has 60 bunches; the energy is 100 Joules; the average energy density is 7 J/g for E-= 10 GeV and an amorphous thickness of 8 mm. The PEDD is 20 J/g for a nominal PEDD of 0.33 J/g/bunch

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- **COMPARISONS BASELINE/HYBRID**
- **Rate of deposited energy:**
- **# For the baseline (EPAC08), the ILC bunch is carrying 10J with 10^{13} photons. 8 % of this energy is deposited in the target.**
- **# For the hybrid source, @ E-=10 GeV, and 8 mm thick amorphous target, the number of photons from the crystal per ILC bunch is: $4.8\times10^{11}\,\gamma$ and the deposited energy [1.7 J] represents 10 % of the incident energy (17 J)**
- **Energy Density:**
- **# For ILC baseline, the energy density is of 40 J/g (Ti)**
- **With a wheel rotating at 100 m/s**
- **# For the Hybrid/LAL source, the energy density is 32 J/g (W) for a wheel rotating at 31.4 m/s**

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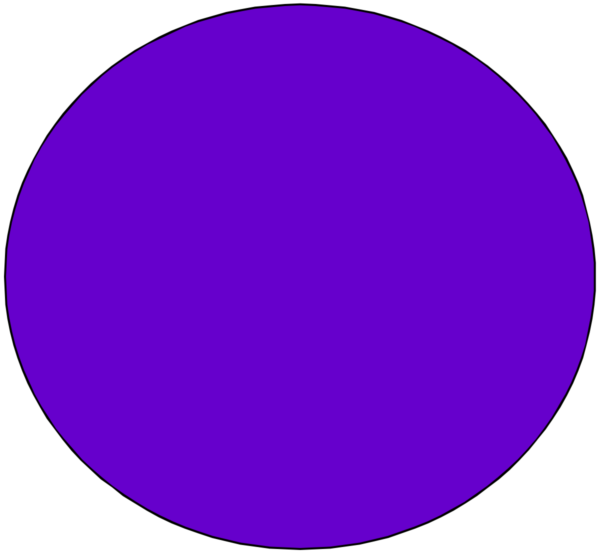
- **THE UNDULATOR CASE (I.Bailey)**
- **The targets are on a wheel**
- **1 meter diameter rotating**
- **At 2000 rpm and with**
- **tangential velocity of 100 m/s**
- **The energy deposited in the**
- **target is 0.8 J/bunch**
- **Photon beam spot is ~1-2 mm**
- **radius. The average energy**
- **density is, then, of 40 J/g for**
- **the rotating target.**



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- **Some comparisons concerning PEDD, Shock waves,...**
- **We recall that the PEDD/e- in a 8 mm amorphous target submitted to γ emitted from 1mm crystal under 10 GeV e- is of ~2 GeV/cm^3**
- **For the ILC the average deposited power in 8 mm target is ~20kW**
- **1/Solution A (KEK):**
- **For each triplet (~1μs): PEDD 44 J/g :2.6x10^{12}**
- $\tau_p = 1\ \mu s \quad < \quad \tau_s = 3\ \mu s$
- The pulse width is smaller than the time needed by the shock wave to travel from the surface to the centre for a target r=L=1cm
- **2/ Solution B (LAL)**
- **For each micropulse (~22.14 μs): PEDD 20J/g: 1.2x10^{12}**
- $\tau_p = 22.14\ \mu s > \tau_s = 3\ \mu s$
- Time needed for the shock wave to travel from the outer surface to centre

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- **SOME COMPARISONS…**
- **Rotation speed of the target wheel**

Baseline	LAL scheme	KEK scheme
100 m/s	31.4 m/s	2-4 m/s

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- **PRELIMINARY CONCLUSIONS**
- **We have presented an approach for using an hybrid positron source for ILC. The advantages of such a system is to lower the PEDD values on the converter, using only the photons from channeled electrons in a thin crystal. The simulations done are showing that:**
- **# modifying the ILC macropulse time structure before the target, creating a set of micropulses (20or 44) it was possible to lower strongly the energy deposited in a pulse and hence the corresponding PEDD. The choice of the micropulse duration and of the separation between successive micropulses is also essential to allow the shock waves associated to the thermal pulses to damp enough. That seems possible. The nominal time structure is restored with the DR. The modified time structure is compatible with the needed damping times.**
- **# to absorb the average power a rotating target seems necessary but with lower velocity than with the baseline solution. An accurate study of that rotating target is underway considering both options KEK & LAL.**

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- **PRELIMINARY CONCLUSIONS (continued)**
  - **Optimization?**
  - **The optimization of the source parameters can be done with respect to the following factors of merit:**
  - **# [accepted yield]/PEDD => maximize {thinner targets and lower incident energy}**
  - **# Deposited energy density => minimize {larger e-beam dimensions}**
  - **# [pulse duration]/shock wave time propagation**
  - **=> maximize {choice of large enough pulse duration}**
  - **# Target rotation speed: => minimize**
  - **# Positron preaccelerator acceptance: => maximize**
  - **{choice of L-Band instead of S-Band}**
  - **Develop a precise quantitative approach for calculating the effects of thermal shock waves :finite elements**