GRANULAR VS COMPACT POSITRON CONVERTERS:ADVANTAGES & APPLICATIONS TO HYBRID SOURCES

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Presented by P.Sievers

GRANULAR VS COMPACT POSITRON CONVERTERS…

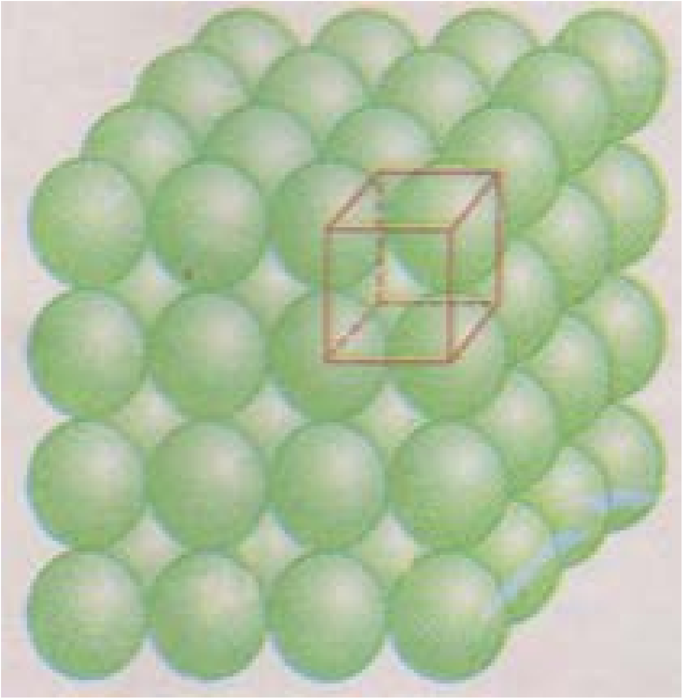
- PLAN
- * Introduction
- * Description of the granular target
- * Comparison granular/compact target
- * Advantages of the granular targets (thermal dissipation, PEDD,.
- * Optimization of the granular target: sphere radius, number w.r.t. beam dimensions, pulse duration, …
- * Application for a hybrid e+ source using channeling; cases of ILC &CLIC
- * Possible test with a granular target (at KEK); what and how to measure
- * summary and discussions.

GRANULAR VS COMPACT POSITRON CONVERTERS…

- **INTRODUCTION**
- **One of the main problems for the positron converters, dedicated to the future linear colliders, is the high amount of deposited energy due to the high intensities required in the LC. Cooling may be very complicated to evacuate the high amount of heat. Since some years, a particular shape for the targets delivering high beams of pions under proton incidence, has been considered by P.Sievers et al for the neutrino factories. Instead of using compact targets, granular ones made of a large number of small spheres were considered. The idea is based on the high ratio surface/volume of the spheres which makes easier the heat dissipation. Such idea is now investigated for the positron converters and a first application was studied for ILC positron source in the PhD thesis of C.XU (defended in May 2012 at IHEP/Beijing). In this application, the positrons were generated by an intense beam of photons emitted by ultrarelativistic channeled electrons in an axially oriented crystal. We present, here, the main advantages of such converters with a particular emphasis for the ILC case: the conditions for a beam test are also examined.**

GRANULAR VS COMPACT POSITRON CONVERTERS…

- **GRANULAR CONVERTERS: A PRESENTATION**
- **The target is made of small spheres**
- **with radii of ~ 1 mm. The spheres are**
- **put in a container with a low Z (Be,**
- **for instance). The best suited cooling**
- **is based on a Helium gas jet circulating**
- **between the spheres and taking off**
- **the heat.**



GRANULAR VS COMPACT POSITRON CONVERTERS…

- **COMPARISON BETWEEN COMPACT AND GRANULAR TARGETS**
- **- Simulation results (with hybrid source using channeling radiation)**
- **A comparison has been carried out between granular and compact targets: the compact one was chosen as to satisfy the ILC requirements for the positron yield. The granular targets were chosen to be as close as possible to the compact one concerning the yield. A table is summarizing this comparison**

	thickness	yield	PEDD	(ΔE)dep	N-layers	spheres number	Effective density
unity	mm	e+/e-	GeV/cm³/ e-	MeV/e-			g.cm⁻³
compact	8	13.3	2.24	523			19.3
Granular r=1mm	10.16	12.5	1.8	446	3	864	13.9
Granular r= 0.5mm	11.60	13.45	2.33	613	7	8064	13.9

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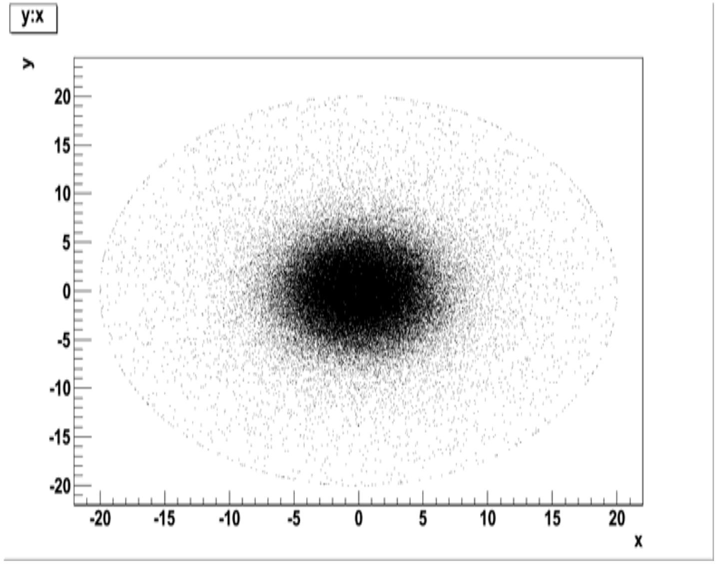
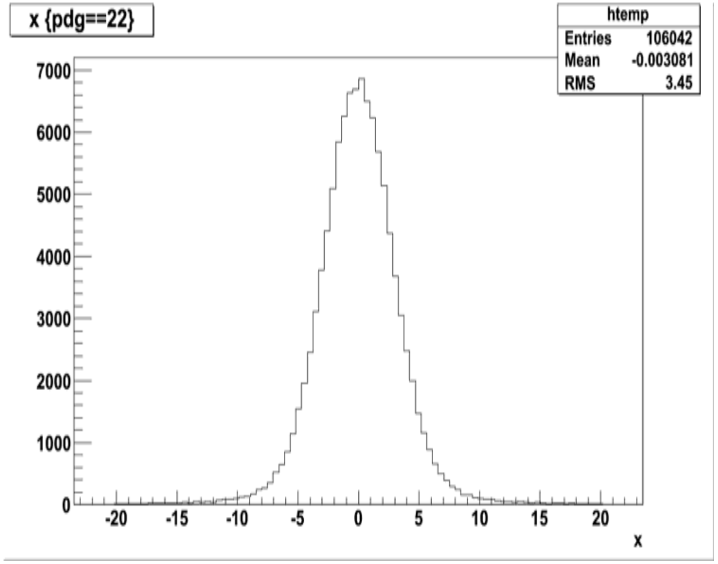
- **SIMULATIONS WITH A HYBRID SOURCE**
- **The following results are obtained with an hybrid source using a W crystal, 1 mm thick on which a 10 GeV e- beam is impinging; rms transverse radius of e- beam is 2.5 mm. An illustration of the γ beam is given:**

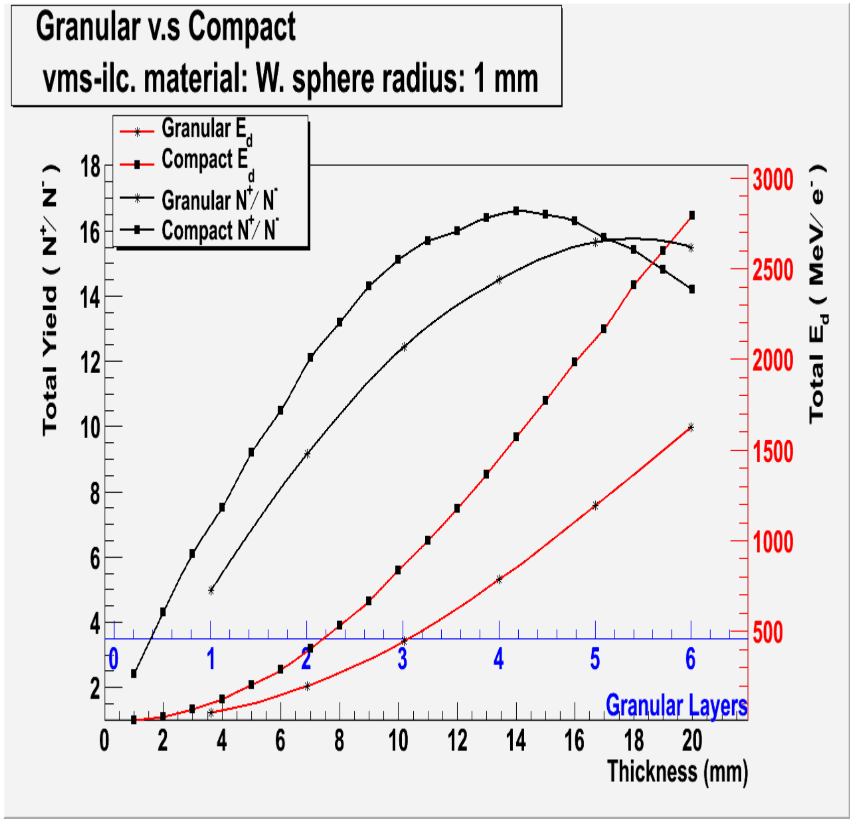




GRANULAR VS COMPACT POSITRON CONVERTERS…

- COMPARISON GRANULAR/COMPACT

- The yield and total deposited
- energy/incident electron have
- been simulated for a compact
- and a granular target
- (w.r.t. the number of layers).
- We can see, here, that a granular
- target with 3 layers has slightly
- lower yield than the compact
- one (8 mm thick) and the energy
- deposited is weaker. The choice
- of the 3-layer granularity is
- convenient
- .



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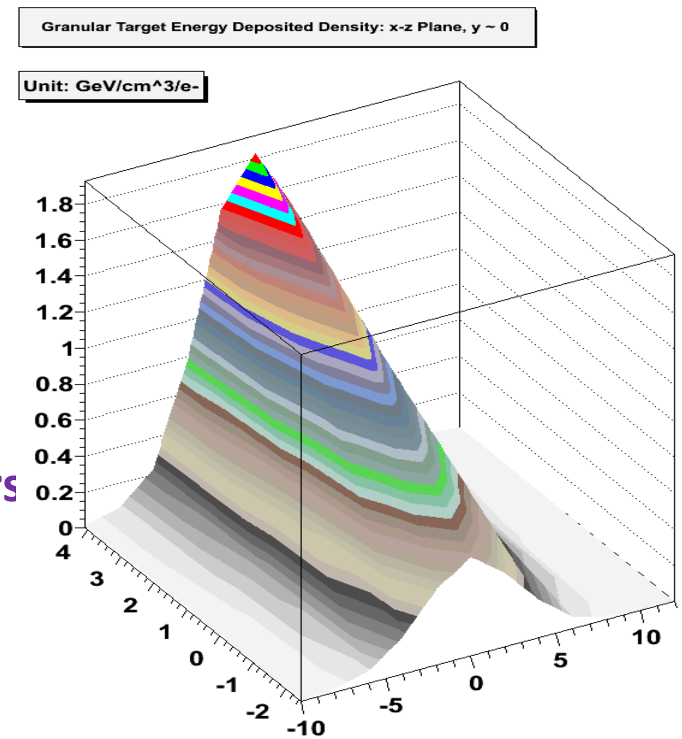
- **PEDD**
- **The PEDD has been also simulated in the amorphous compact/granular converter. The results of the simulations are given. We can notice the interest of the granular converter w.r.t.**
- **the compact one.**
- **We have chosen to modify the beam**
- **time structure, following the**
- **proposition of Omori et al, to reach**
- **a reasonable amount of energy**
- **deposition density in the converter.**
- **The granular converter is made of 3 layers**
- **=>> Energy deposition: 446 MeV/e-**
- **=>> PEDD; 1.8 GeV/cm3/e-**



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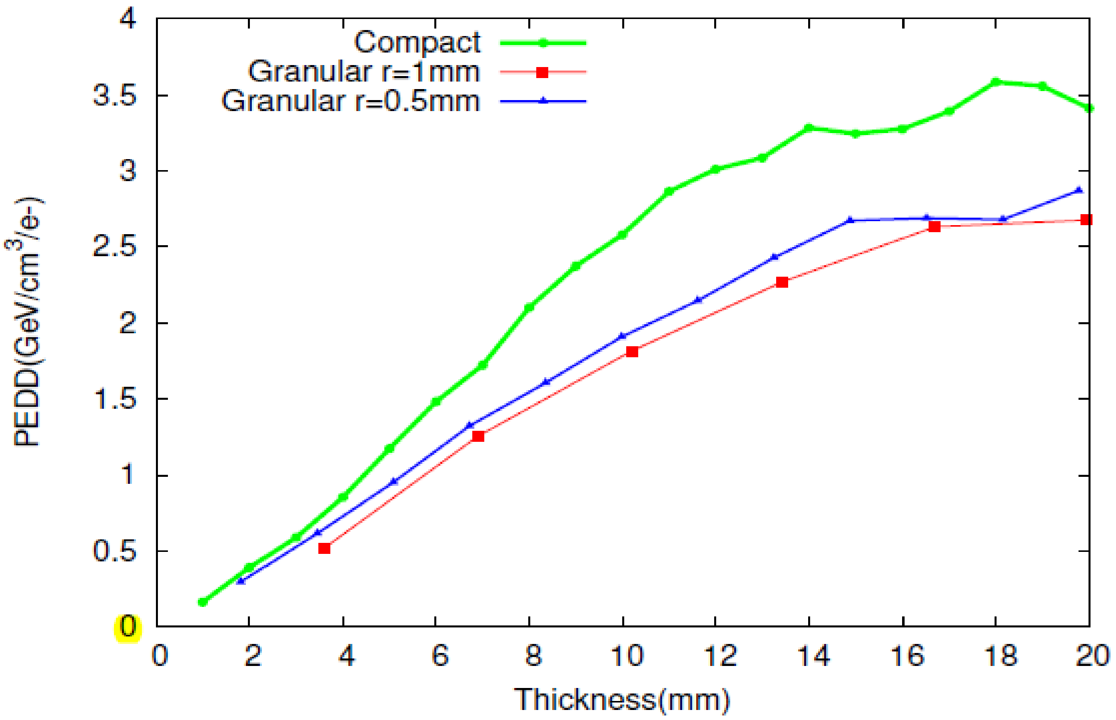
COMPARISON GRANULAR/COMPACT→PEDD:

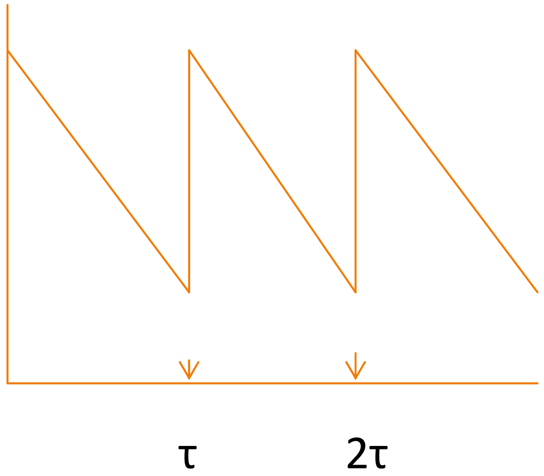
The data corresponds to ILC case=>> E-=10 GeV; l(Xtal)= 1 mm



(c) PEDD

GRANULAR VS COMPACT POSITRON CONVERTERS…

- **ADVANTAGES OF THE GRANULAR TARGETS**
- **If we consider the convective cooling in a pulsed**
- **temperature regime, the decay time is given by:**
- $\tau = C.m/\alpha.F$
- **Where C is the specific heat, m, the sphere mass,**
- **α, the convection cooling coefficient, and F, the**
- **sphere surface. This expression may be written:**
- $\tau = C.\rho.R/3.\alpha$
- **With ρ, the density and R the radius of the sphere;**
- **As for a sphere, F/V is 3/R**
- **it shows clearly that a fast cooling requires small R value. So, using small spheres present a real interest to ensure rapid cooling. However, some practical limit to small radii is leading to the choice of R~ 1 mm, at least.**



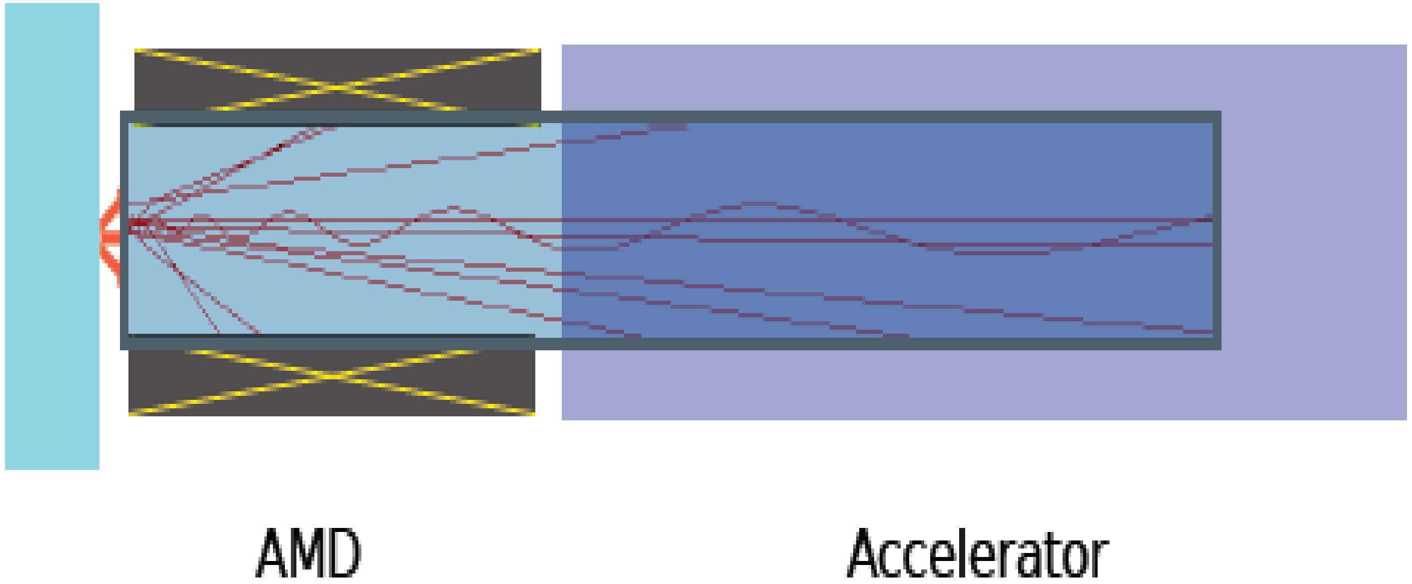
(The decay is exponential)

GRANULAR VS COMPACT POSITRON CONVERTERS…

- **OPTIMIZATION OF THE GRANULAR CONVERTER**
- **The parameters to be optimized are: the radius with respect to the beam duration, the beam transverse dimensions…The physical processes taken into account are:**
- **- the energy deposited by pulse in one sphere**
- **- the PEDD in the "hottest" sphere**
- **- the shock waves**

GRANULAR VS COMPACT POSITRON CONVERTERS…

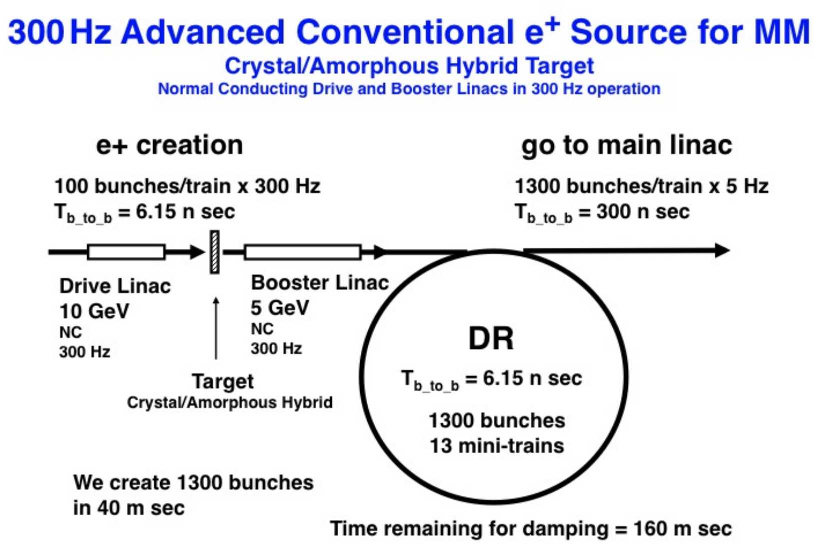
APPLICATION TO ILC: THE POSITRON BEAM EXITING THE GRANULAR CONVERTER



GRANULAR CONVERTER

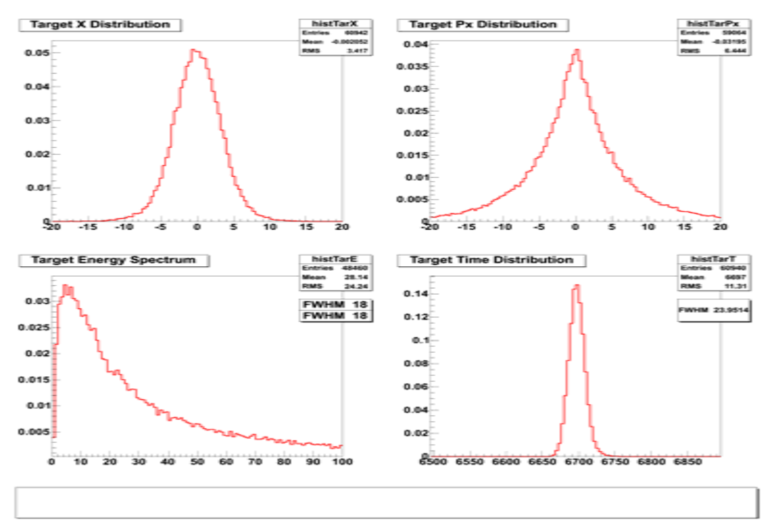
GRANULAR VS COMPACT POSITRON CONVERTERS…

- THE SCHEME FOR ILC:
- The possibility of using the hybrid source (or any solid target) for ILC is related to the ability of transforming the long and intense ILC macropulses into many micropulses (or minitrains) allowing to the heat charge to relax between the micropulses (or minitrains). One interesting solution was proposed 3 years ago by T.Omori. The number of bunches is matching with the most recent parameters for ILC.
- Number of bunches: 100/minitrains
- Number of minitrains: 13/macropulse
- Frequency of minitrains: 300 Hz
- Time width of macropulse: 40 ms
- Simulations on the hybrid e+ source have
- been operated with 2 kinds of converters:
- - compact converter
- - granular converter
- (see PhD thesis of C.Xu)
-

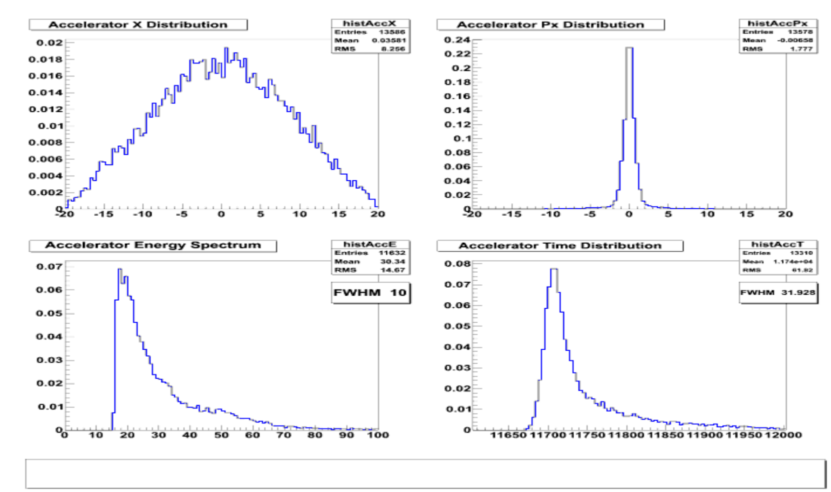


GRANULAR VS COMPACT POSITRON CONVERTERS

- **- Simulations results on positron beam**
- **The positrons created in the granular target (3 layers) are captured by an AMD.**
- **The AMD has the following characteristics:6T-0.5Tand L=50cm. Energy**
- **spectrum, transverse dimensions and momentum are given.**



At target exit



After capture and acceleration

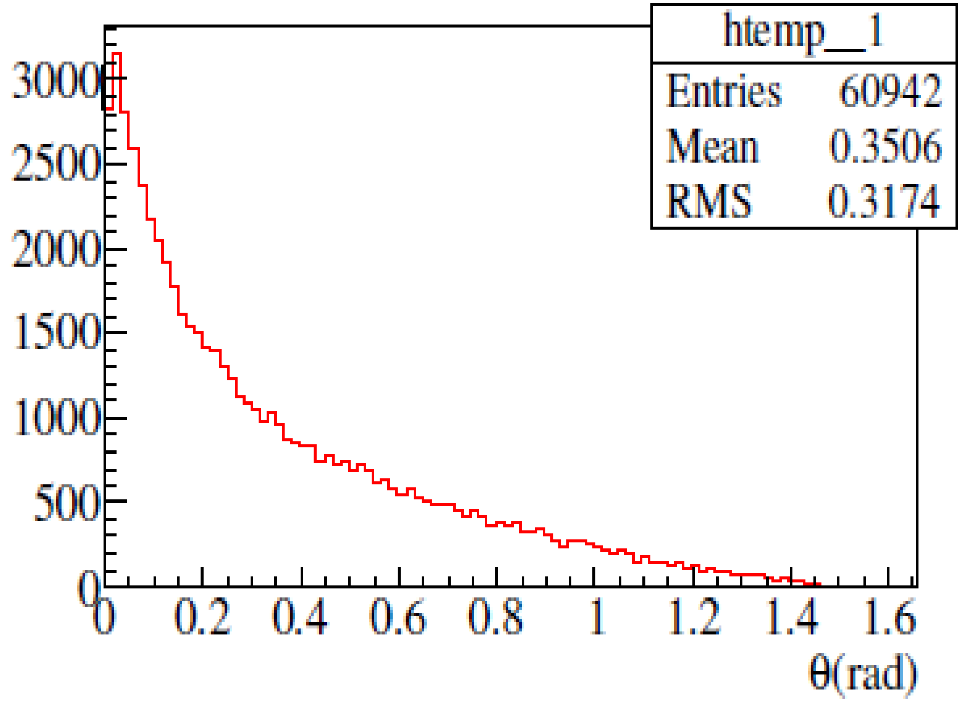
GRANULAR VS COMPACT POSITRON CONVERTERS…

SIMULATIONS RESULTS ON POSITRON BEAM

ANGULAR DISTRIBUTION OF THE POSITRONS AT EXIT OF THE GRANULAR CONVERTER

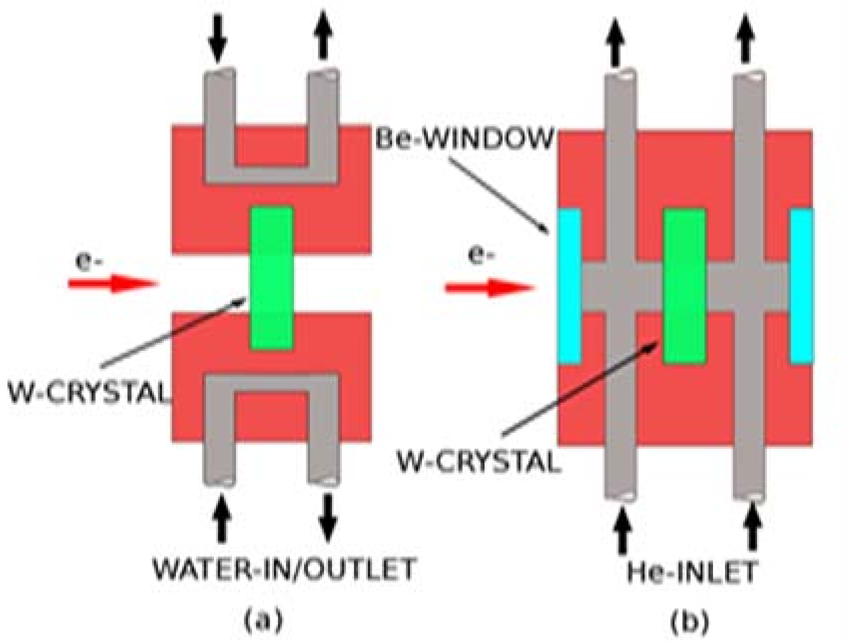
The parameters are those for ILC

Due to multiple scattering the angular spread is large: θ ~0.32 rad rms , about 20°



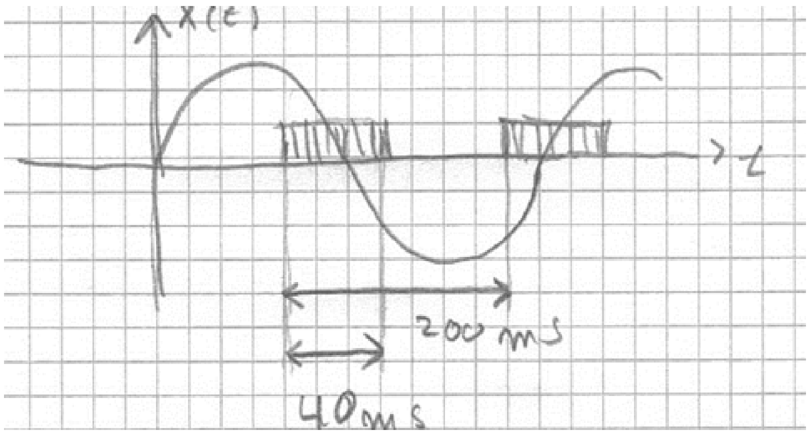
GRANULAR VS COMPACT POSITRON CONVERTERS…

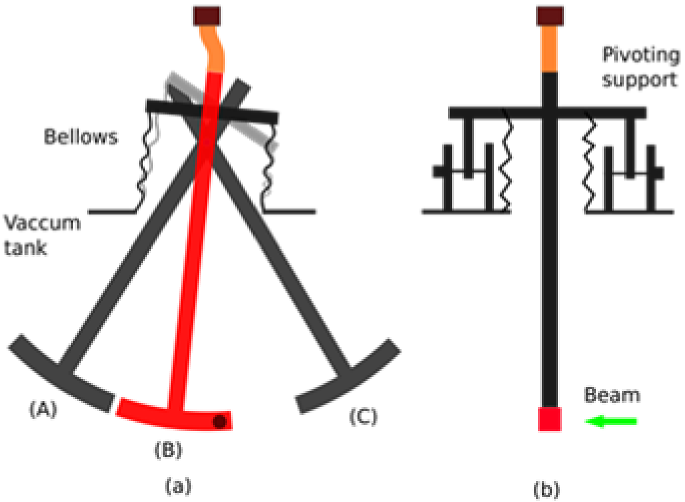
- APPLICATION TO ILC: HEATING AND COOLING FOR THE HYBRID SOURCE
- THE CRYSTAL;
- The crystal must be cooled in order
- to preserve its qualities. A stationary
- crystal, which receives 5 pulses/second,
- leads to important increases
- of temperature: 275 °C (water cooled)
- and 406 °C, He cooled. So, we consider
- an array of 5 crystals with a transverse
- displacement of 5 cm/s. In that case,
- a crystal is receiving 1 pulse/second and
- the temperature rise is of 178 °C (water)
- and 365 °C (He).



GRANULAR VS COMPACT POSITRON CONVERTERS…

- **PENDULUM;**
- **For cooling the granular converter, a**
- **stationary target is irrealistic ; a moving**
- **Target is needed. To place the μpulses**
- **Besides each other, the speed is**
- **1cm/3.3 ms =>> 3m/s. The time sharing**
- **between beam on and beam off is:**

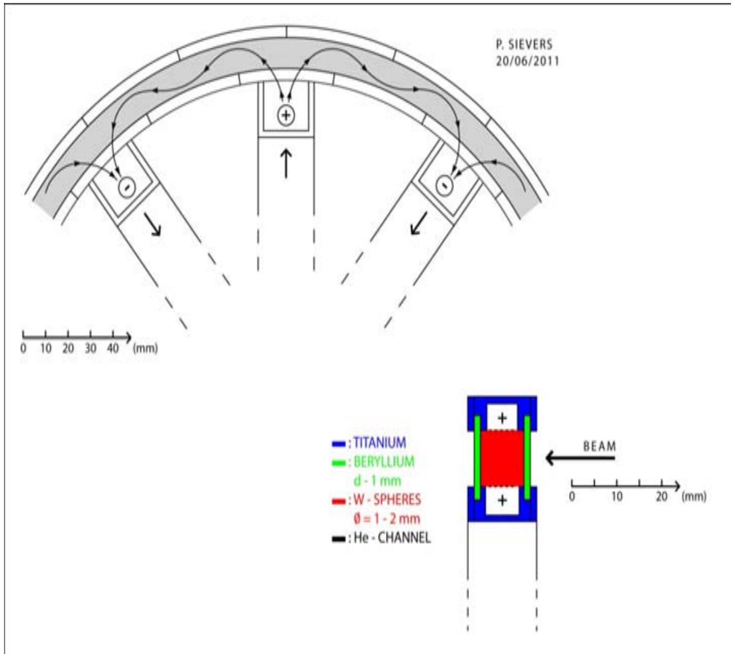




The arc length is 13 cm and the frequency is 2.5 Hz

GRANULAR VS COMPACT POSITRON CONVERTER…

- **THE ROTATING WHEEL:**
- **The wheel diameter is 58 cm ; there are**
- **182 places for the µpulses. The**
- **rotation is: 100 rpm. A He flow is**
- **Circulating to cool the spheres. Be**
- **Windows are at upstream and**
- **downstream faces of the target.**



GRANULAR VS COMPACT POSITRON CONVERTERS…

SUMMARY FOR THE TEMPERATURES IN CRYSTAL AND CONVERTER

	Single Crystal	5 Crystals	Pendulum		Rot.Wheel	
	W	W	W	Be	W	Be
PEDD J/g	5.83	5.83	31.5	30.6	31.5	30.6
T/micro K	41	41	222	16.3	222	16.3
En./microp. J	2.6	2.6	146	3.4	146	3.4
Av.Power W/Targ.	170	34	730	17	52	0.24
Max. Temp oC,[He]	. 406	365	420	186	242	36
Max. Temp oC,[Water]	. 275	178	250	-		-

Table 2 Summarizing table Brackets indicate the cooling case

GRANULAR VS COMPACT POSITRON CONVERTERS…

- **STRESS WAVES IN RAPIDLY HEATED W SPHERES**
- **Data: ρ= 19.3 g/cm³ ; C =5.26x10 ³m/s (sound velocity); ν =1/3 (Poisson ratio)**
- **CLASSICAL APPROACH:**
- $$\frac{\partial 2F}{\partial r2} = \left(\frac{1}{c2}\right)\frac{\partial 2F}{\partial t2} \quad ,$$
-
- **Where F is the velocity potential. The general solution is such:**
- **$F = \vec{f}(r-ct) + \overleftarrow{g}(r+ct)$**
- **The displacement is expressed by:**
- **U(r, ct)= ∂/∂r(F/r)**
- **The stress is expressed by:**
- **σ_r (r, ct) = (3/2)E{∂U/∂r +U/r}**
- **σ_φ (r, ct) = (3/4)E{∂U/∂r +3U/r}**

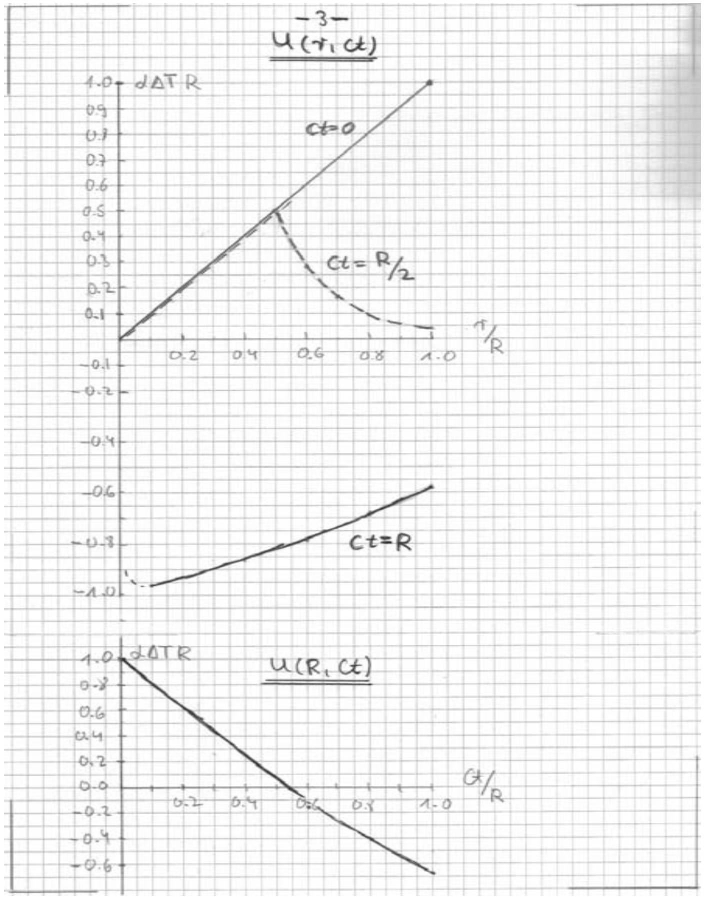
GRANULAR VS COMPACT POSITRON CONVERTERS…

- INITIAL CONDITIONS: ct=0; Instant:ΔT
- U(r, ct=0) = αΔTr ; α, being the linear coefficient of thermal
- expansion
- dU/dt = 0
- $\sigma_r(r, 0) = \sigma_\varphi(r,0) = 3E\sigma\Delta T$
- Boundary conditions :
- Free outside the surface; $\sigma_r(R, ct) = 0$
- At center: U(0, ct) =0
- ∂u/∂t (0, ct) =0
- The solutions can be written down in closed form:
- Consider U(r, ct); $\sigma_r(r, ct)$; $\sigma_\varphi(r, ct)$ for 0<ct < R and 0<r<R

Some results for R<ct<3R/2 and 0<r<R/2

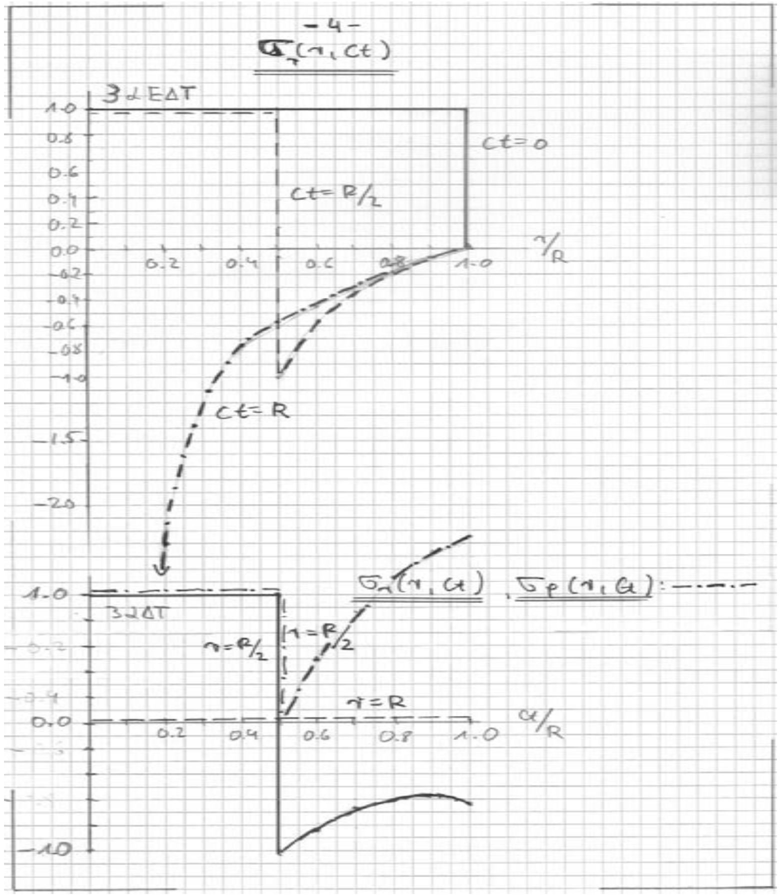
GRANULAR VS COMPACT POSITRON CONVERTERS…

- **DISPLACEMENT: U**



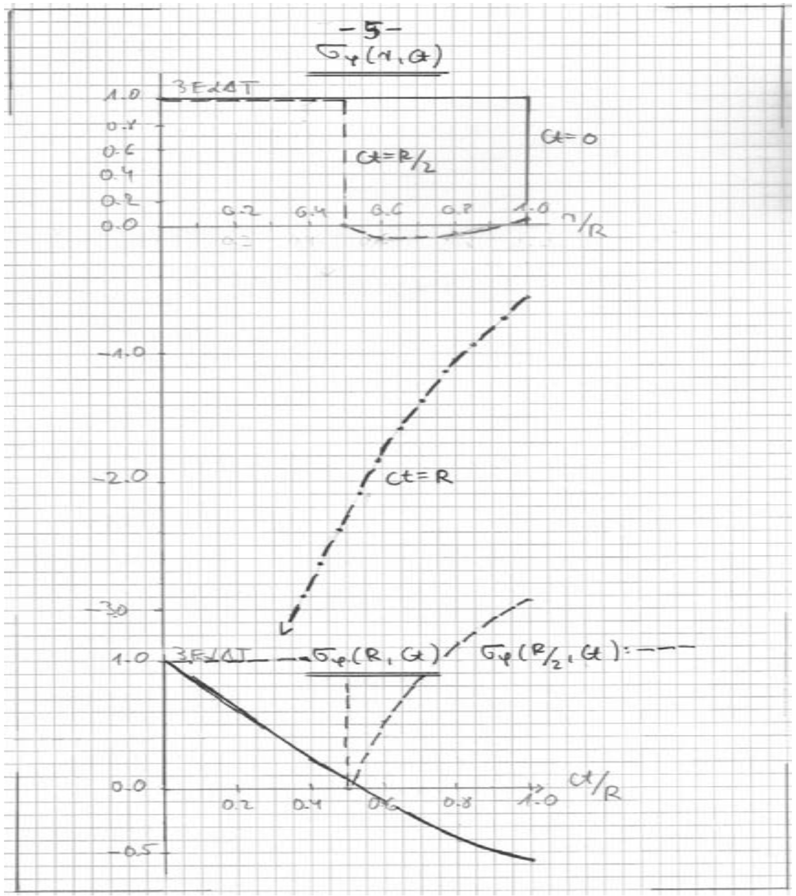
GRANULAR VS COMPACT GRANULAR CONVERTERS…

- **RADIAL STRESS : σ_r (r, ct)**
- **AZIMUTHAL STRESS: σ_φ (r, ct)**
-



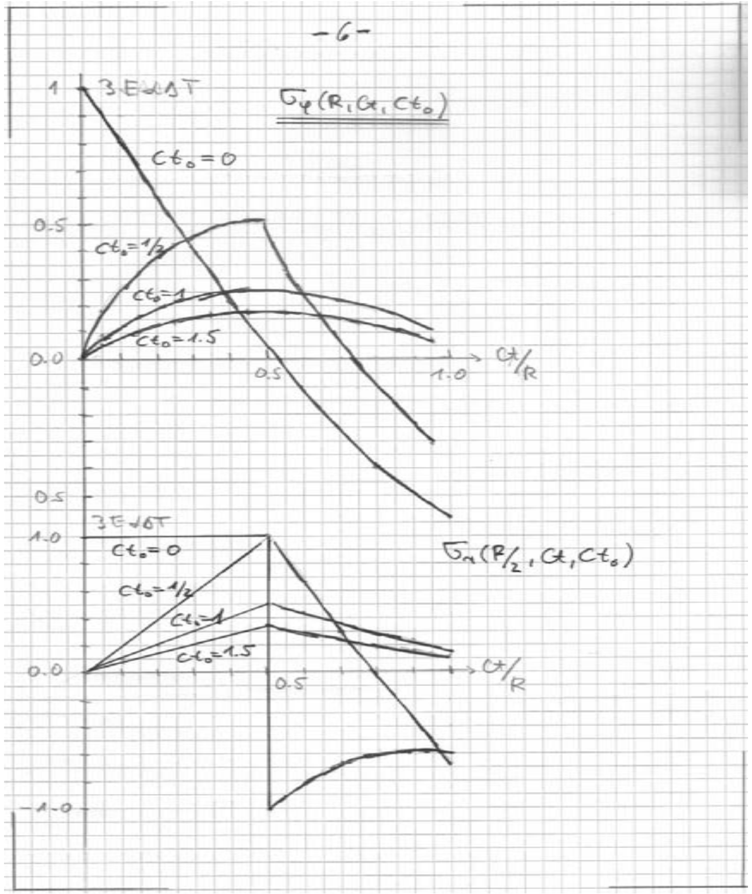
GRANULAR VS COMPACT POSITRON CONVERTERS…

- **AZIMUTHAL STRESS: σ_{φ} (r, ct)**
-



GRANULAR VS COMPACT POSITRON CONVERTERS…

- **AZIMUTHAL AND RADIAL STRESSES**
- **σ_{φ} (R, ct, ct_0) and**
- **σ_r (R/2, ct, ct_0)**



GRANULAR VS COMPACT POSITRON CONVERTERS…

- SUMMARY AND CONCLUSIONS
- * THE HYBRID POSITRON SOURCE: Using mainly the photons, emitted by high
- energy electrons in an axially oriented crystal, to generate the positrons in a
- thick amorphous converter we obtain promising results concerning the positron
- yield
- * THE GRANULAR CONVERTER: presents promising characteristics for the energy
- deposited and the PEDD which are better than for a compact target.
- * AN APPLICATION TO ILC: modifying the beam time structure of the ILC beam
- following a suggestion by OMORI-san (300 Hz solution) it has been possible to
- describe an unpolarized hybrid positron source using a granular converter and
- fulfulling the requirements of ILC for the yield, the PEDD and with appropriate
- cooling systems involving reasonable speeds for the moving targets.
- *

GRANULAR VS COMPACT POSITRON CONVERTERS…

- **CONCERNING THE STRESSES:**

- **For the Hybrid System the instantaneous temperature rise**
- **in a W-sphere is**
- **$\Delta T = 232$ K.**
- **With a Young's Modulus of**
- **$E = 40 \times 10^4$ MPa**
- **and a thermal expansion coefficient of**
- **$\alpha = 4.5 \times 10^{-6}/°K$**
- **the instantaneous thermal stress in a sphere will be**
- **$\sigma = 3\ \alpha E\ \Delta T$,**
-
- **$\sigma = 1250$ MPa (82 % of the elastic limit).**
-
- **Open questions: Can small W-spheres still be considered as an ideal, amorphous, elastic medium, as assumed in the stress propagation analysis. There may be micro cracks, crystalline micro-structures, ….? What will be the fatigue limit and the life time?**

GRANULAR VS COMPACT POSITRON CONVERTERS…

- **CONCERNING THE STRESSES (continue):**

- **For the ILC the pulse duration is about**
- **τ = 0.6 µs.**
- **The transition time of sound through the 2 mm spheres is**
- **t = 0.2 µs.**
- **We observed stress reductions by a factor 2-3 for pulse durations of**
- **τ = 0.1…..0.3 µs, cto = 0.5…..1.5 mm**
- **at the regions of R/2….R.**
- **Expect further stress reductions with larger pulse durations of τ = 0.6 µs at the outer part as well as at the centre of the spheres. =>> Still to be done!**

GRANULAR VS COMPACT POSITRON CONVERTERS…

- **Experimental verification and benchmarking of the Granular Target are necessary.**
-
- **The PEDD can be measured by measuring the temperature rise via thermo couples and infrared camera at the rear of the granular target. Can be made at lower than nominal beam intensities. First Results were presented by T. Suwada, T .Takahashi and T. Omori of KEK.**
-
- **Thermal shock: One would require tests with a nominal gamma-beam and with the proper pulse duration of 0.6 µs.**
- **Tests with equivalent electron or proton beams may also be possible.**
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